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AIR POLLUTION CONTROL IN THE PRIMARY ALUMINUM INDUSTRY

VOLUME I. SECTIONS 1 THROUGH 10

Singmaster and Breyer

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SINGMASTER & BREYER
235 East 42nd Street
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REPORT IN BRIEF

A study was made of the technical and economic aspects of the emissions and control of air pollutants in the primary aluminum industry for the Environmental Protection Agency under Contract No. CPA 70-21, and was completed in late 1971. The cost and performance data base for the study included detailed information supplied ~~to the contractor~~ in confidence by the domestic producers, typical performance data obtained from equipment suppliers, and published information from the technical literature. Engineering analysis of the data ~~by the contractor~~ resulted in systems evaluation of current industry control in terms of present costs and performance. Systems analysis was applied to growth projections at various control levels to estimate future costs and emissions. Recommendations were made covering the direction of research and development efforts towards improvement in pollution abatement by the industry.

The Industry

The domestic primary aluminum industry is based on the electrolytic reduction of alumina, most of which is either directly imported or produced from imported bauxite. At the end of 1971 there were 30 reduction plants, operated by 13 producers, distributed among the Pacific Northwest, the Gulf Coast, and the East Coast sections of the United States. The industry has grown since 1946 at an average rate of 10.2 percent, and in 1970 had reached a production rate of nearly 4 million short tons per year. United States capacity was some 46.6 percent of the world total.

Industry growth is expected to continue to respond to the long term steady increase in demand, and domestic primary production is expected to double or triple by the end of the century.

Technology of Aluminum Production

Primary aluminum metal is produced by the Hall-Heroult process involving the electrolytic reduction of the aluminum oxide (alumina) dissolved in a molten electrolyte of sodium aluminum fluoride (cryolite). Carbon anodes are immersed in the bath contained in a carbon lined cell which acts as the cathode.

Approximately 7-8 kwh of direct current is consumed per pound of aluminum metal produced. From 90 to 180 reduction cells are connected electrically in series to form a potline, the basic production unit of the reduction plant.

The molten aluminum metal produced has a slightly greater specific gravity than the cell bath, and collects as a layer on the bottom of the cell, from which it is periodically syphoned and transferred to a cast house.

As electrolysis progresses, the alumina content of the bath is decreased, and is intermittently replenished by feed additions to maintain the content at about 2 to 5 percent in solution in the cryolite. When this content falls to about 1.5 to 2.0 percent, the phenomenon of "anode effect" may occur, in which the bath fails to wet the carbon anode and a gas film collects under the anode. This film causes a high electrical resistance and the normal cell voltage increases 10-15 fold. Correction is obtained by addition of alumina to the bath.

Bath composition is adjusted by addition of aluminum fluoride and cryolite as required to obtain maximum current efficiency.

Reduction cells are of two basic types, the prebake cells using multiple prebaked carbon blocks as anodes, and the Soderberg cells using large single anodes which are charged with carbon paste and continuously baked in place. Prebaked anodes are replaced periodically by new assemblies and the butts recycled for reclamation and re-use in the anode preparation plant.

Soderberg anodes are completely consumed; the in-place baking of the anode paste results in the release of hydrocarbon fumes and volatiles derived from the pitch binder of the paste mixture. These components of the Soderberg effluents, which are essentially absent from the prebake cell gases, require modification of the effluent treatment techniques applied to emission control from the reduction cells.

The preparation of anode materials is usually an ancillary operation at the reduction plant site. A carbon plant, or "green mill", crushes and sizes coal and coke, mixes them with pitch, and produces Soderberg anode paste or green anodes. The latter are fired and baked, and assembled with connectors for use in the cells. Return prebake butts are cleaned and then recrushed for incorporation in the green anode mix.

Molten cell metal is transferred to a cast house where it is fluxed to remove trace impurities and cast into a variety of ingot forms.

Fluoride losses from the potline operations occur as cryolite absorption into cell linings and as evolution and dusting of fluorides from the cell surfaces. The latter, about three quarters of the total, presents the major portion of the potential pollutant emission of the primary aluminum reduction operations. Approximately one-third of the fluorine content of the cell effluent is in the form of particulate fluorides, some of which are susceptible to direct mechanical separation and recovery as dry recycled return feed. Finer sizes of fluoride particulates present greater removal difficulty and are a potential source of pollutant emissions. Gaseous fluorides, evolved directly from the cell or formed by hydrolysis from other fluorine compounds, are amenable to nearly complete emission control by chemisorption on alumina or by solution in aqueous media.

The economics of fluorine replacement of losses from the reduction cell favor maximum recycle of fluorine in a form which can be directly added as cell feed without the need to be reconverted to cryolite for this purpose.

Effluents

The airborne effluents from primary aluminum reduction plant operations include dusts of carbon and alumina from materials handling and preparation, and particulates and gases evolved from potlines, anode bake furnaces, and cast house. Of these, the dusts present an in-plant problem of industrial hygiene and housekeeping; the bake plant effluents are primarily a smoke abatement problem and the cast house effluents, mainly chlorides from intermittent metal fluxing operations, may not be of significance. The potline effluents are the greatest quantity and potentially the most damaging.

Composition and quantity of potline effluent vary within wide limits among the plants in the aluminum industry, being affected by type of cell installation, and potline operating conditions. The most significant components from a pollutant viewpoint are fluoride particulates, gaseous fluorides and nonfluoride particulates. Sulfur dioxide (derived from sulfur content of the anode content) may or may not present a pollutant problem, depending on plant location. Effluent generation rate, per 1000 pounds of aluminum* made in prebake potlines is of the order of:

	Lb/1000 lb Al
SO_2	30
"F" as gaseous fluorides	14
F as solid fluorides	9
Total F	23
Total Solids	46

Effluents from Soderberg cells include, in addition, volatilized hydrocarbons at the cell operating temperatures.

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* Throughout this report, most effluent and emission rates are expressed as pounds per 1000 pounds of aluminum production, equivalent to kilograms per tonne.

Bake plant effluents may include products of firing combustion, burned and unburned hydrocarbons derived from the heating and carbonizing of the paste binder pitch, sulfur oxides derived from the carbon paste materials, and fluoride. The order of magnitude of these effluents is:

	Lb/1000 lb Al
Total Solids	1-5
Hydrocarbons	0.25-0.75
Total F	0.15-0.75
Sulfur (in oxides)	0.35-1.0

Cast house effluents are largely fumes of aluminum chloride which, in the presence of atmospheric moisture may hydrolyze to HCl and Al_2O_3.

Emission Sampling

The problems of obtaining representative samples of effluent and emission streams in the primary aluminum plant to determine the effectiveness of pollution abatement are discussed. They are concerned with the difficulty of accurately sampling very large volumes of low velocity air flow in secondary collection systems, complicated by low particulate and gas loadings, by non-uniform content of the gas systems, and by water saturation of the gas stream after wet scrubbers. More dependable sampling can be made in the primary collection systems. Sampling techniques to obtain isokinetic samples are discussed, as are the problems of differentiation of solid and gaseous fluorides due to the high reactivity of the gaseous fluorine compounds.

Note is taken of the need to correlate particulate emission size distribution with settling velocities and conditions which affect dust-fall and ambient air quality in peripheral areas. Sampling equipment, including particulate separation and gas trains, are discussed. References are given for analytical methods.

Reported Industry Effectiveness and Cost of Emission Control

Based on confidential quantitative information furnished by the primary aluminum producers in response to a detailed questionnaire, reported industry emission control practice was analyzed and summarized.

The weighted average effluent rate from carbon anode bake plants was calculated to be of the order of 214 standard cubic feet per pound of prebake plant aluminum capacity, with gas loadings of 0.015 grain total gaseous fluoride and 0.085 grain total particulates per standard cubic foot. Fluoride in particulates was reported to be negligible. No emission data on anode bake plants was reported by industry, although some 40% of the bake plants capacity is under some sort of control, much of it experimental.

The weighted average emission control data reported by the industry for all types of potlines which exercise some control are shown in the following tabulation. While the responses represented some 93% of the industry tonnage, not all provided breakdowns of gaseous and particulate fluoride data, and the weighted averages are regarded as representing good orders of magnitude rather than exact data.

	Lb/1000 lb Aluminum Produced			
	Total Solids	Solid "F"	HF	Total "F"
Cell Effluent	47.7	8.8	13.1	22.5
Primary Collection System	40.3	7.5	11.7	19.3
Secondary Collection System	6.9	1.1	1.2	2.3
Primary System Emission	5.9	1.6	0.9	2.3
Secondary System Emission	6.4	1.1	1.2	2.3
Total Emission	12.3	3.0	2.1	5.1
Overall Emission Control Efficiency*	73%	66%	84%	77%

* Based on reported data from most of the controlled segment of the United States aluminum industry.

The emission from the domestic primary aluminum industry on a 1970 production of 4.0 million tons of metal are estimated to have been as shown below:

	Tons Emissions (1970)		
	Potrooms	Bake Plants	Total
Total Fluorine	23,200	650	23,800
Gaseous Fluorides	10,200	600	10,800
Fluorine in Particulates	13,000	50	13,000
Total Solids	53,000	4,200	57,200

Ninety-seven percent of the potline tonnage reported some degree of emission control on their effluents.

The reported costs of emission control, after adjustment to 1970 dollars and extrapolation to include the 12 percent of controlled tonnage not reported, provided data for an estimate that the total capital investment for installed pollution control for the 1970 annual production capacity of about 4.1 million tons is about $240,000,000, of which $236,000,000 is in potroom pollution control.

It is estimated from the reported data that the total industry annual operating costs for pollution abatement, adjusted to include interest, taxes, insurance and depreciation amount to about $65,000,000 per year.

From the reported data the United States primary aluminum industry, as a whole, has an investment of some $58 per annual ton of capacity in pollution control installation and spends a net of about $16 per ton of aluminum produced to control its emissions to the level of 6.0 pounds of total fluorine (2.7 pounds in gaseous form, 3.3 pounds in particulates) and 14.4 pounds total solids per 1000 pounds of aluminum produced.

Systems Analysis of Pollution Abatement Control

To provide a tool by which the effects of variations in industry-wide levels of emission control could be evaluated in terms of resultant needs for modification of control schemes and consequent costs, plant effluent control models were constructed representative of the combinations of reduction cell types, collection schemes, and emission control devices of the potline units now operating in the industry. These plant models could then be combined by proportional tonnage to obtain an overall model representative of industry performance and costs.

Typical effluent and collection parameters were established from reported industry data as a basis for the determination of plant model performances. Cumulative removal efficiencies of individual control devices used in combination determined the effectiveness of control schemes, and these, applied to the effluent and collection parameters, established the overall control efficiencies and thus the emissions.

Capital and operating costs of the model control schemes were calculated by summation of the costs of the elements, including collection systems, pollutant removal equipment stages for primary and secondary effluent treatment, and cost of scrubber water treatment for recycle.

Equipment purchase costs were estimated from supplier information. Operating costs included credits, where appropriate, for recovered alumina and fluorine values.

Cost effectiveness comparisons were made among model control schemes applicable to collection scheme alternatives used for each type of potline, and relationships were established between overall control efficiency and control cost per ton of aluminum. These comparisons illustrate the strong influence of collection or hooding efficiency on overall control efficiency as well as the orders of magnitude differences of costs associated with the various control efficiency levels for the different potline types.

Industry Control Improvement Analysis by Models

By operating on the individual plant control models which are combined in proportion to the respective tonnages representative of industry practice, systems analysis of the overall industry may be carried out. The degree of industry control can be analyzed and costed, and the effects of improvements in individual process segments of the industry can be evaluated.

Current industry control practice was analyzed in detail through use of the models by cell type, effluent collection systems, and finally by emission control schemes. Comparisons were developed to show the relationships between percent total aluminum capacity of each segment of the industry and the contributions to total fluoride emission inventory, relative control efficiency, and fluoride emission rate per ton aluminum produced.

The base case was used to project the effectiveness of improving the present level of industry overall control efficiency by selectively upgrading individual model schemes to others of higher performance. Unit cost increments involved were applied to the capacity tonnages represented by the model modification, and the resulting cost and emission model of the total industry was restructured.

For these projections, improvements from the present estimated 74.3 percent overall control efficiency were analyzed to estimate performances and costs to achieve the following four levels of improved performance:

> All plants to achieve at least 80 percent overall control efficiency
>
> Apply best demonstrated primary control technology in all plants
>
> Raise all plants to at least 90 percent overall control efficiency
>
> Apply the best demonstrated technology, both primary and secondary, to all plants

The result of the systems analysis, summarized below, illustrates the sharply rising costs involved as higher levels of emission control are achieved by the industry.

A base case, adjusted to capacity constructed at the beginning of 1971, was developed to correlate the results of the systems analysis technique with the adjusted estimates derived from industry reporting through 1969. Good correlation was obtained within the accuracy of the original data, as noted below:

	Estimated From Reported Data 1969 Capy.	Systems Analysis 1971 Capy.
Aluminum, MM Tons	4.0	4.6
Emissions, Total Fluorides		
Annual Tons F	23,200	27,600
Rate, lb F/1000 lb Al	5.8	5.9
Overall Control Efficiency	74.6	74.3
Capital Investment, $MM Total	$236[1/]	$236
Annual Control Cost, $MM	$65[2/]	$61.4[3/]

[1/] Reported direct investment $182 MM.

[2/] Reported direct cost $11 MM without capital charges or credits.

[3/] Includes assigned credits.

Cost Effectiveness of Industry Control Improvement

at 1971 Capacity Level

	Control Level				
	1971 Model	Min. 80% Efficiency	Best Prim. Control	Min. 90% Efficiency	Best Demonstrated Technology
Industry Overall Control Efficiency	74.3	84.0	85.6	90.9	92.5
Emission, Total Fluoride					
Rate, lb F/1000 lb Al	5.9	3.7	3.3	2.1	1.7
Annual Tons	27,500	17,100	15,300	9,800	8,000
Total Control Investment $MM (1970)	$236	$473	$494	$713	$813
Annual Operating Cost $MM/Yr (1970)	$ 61	$119	$116	$201	$200

Future costs of pollution control have been estimated, premised on forecasts of industry capacity growth and on two assumptions for required control level: a) that new capacity will be required to control emissions to the level of best demonstrated technology, and b) that new capacity will be required to apply best demonstrated technology to the primary cell collection stream.

The median of growth forecasts predict total capacity increase to some 22.5 million short tons by the year 2000, with a range in variation of some 30 percent, plus and minus. Cumulative investment and operating costs, will, as capacity replacement occurs, approach those established for the limiting cases of best demonstrated technology, whatever control standards may be adopted by existing plants.

It is estimated that, under these assumptions, the projected industry performance and costs at the year 2000 will be as indicated in the following table:

	Best Demonstrated Primary Control	Best Demonstrated Technology
Aluminum Capacity, MM Tons	22.5	22.5
F Effluent, 1000 Tons	518	518
Overall Control Efficiency, %	94.6	96.5
F Emission, 1000 Tons	28.0	18.1
Total Capital Investment, MM 1970$	1350	2320
Unit Capital, $/Ton	60	103
Total Annual Cost, MM 1970$	202	553
Unit Annualized Cost, $/Ton	9	25

Potential Research and Development Fields for Pollution Abatement

The costs of reaching the presently achievable limit of emission control by best demonstrated technology are high, and the thrust of needed research and development work is towards the reduction of these costs, rather than in closing a technological gap in emission control.

This effort could well be directed towards improvements in cell operations leading to the reduction in the amount of effluents produced by the Hall-Heroult electrolysis process, improvement in the performance of collection and removal equipment which now falls below that of the best systems, and investigation of basic electrochemical inter-relationships affecting fluoride evolution in the Hall-Heroult process to minimize cell effluents.

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1.0 Introduction

The Environmental Protection Agency of the United States Government entered into contract with Singmaster & Breyer, New York, (Contract No. CPA 70-21) to engage in and report on a study embracing technical and economical aspects of the emission and control of air pollutants in the primary aluminum smelting industry. This study, both a survey of the state of the art and a systems analysis of measures to improve pollution abatement, enhances a general understanding of emissions control in the industry and provides guidance in the establishment of control standards.

1.1 Objective of the Study

This study was designed to:

a) Establish a clear understanding of the technical and economic aspects of air pollution control in the primary aluminum smelting industry of the United States,

b) Determine the potential for improving air pollution abatement using existing technology,

c) Estimate present and future costs of control, and,

d) Define areas of investigation which can be benefitted by accelerated research and development.

The present report of this investigation is written with the cooperation of the United States Government Environmental Protection Agency, Office of Air Programs, the United States and Canadian aluminum producers, and manufacturers of equipment useful in the control of aluminum smelter emissions.

1.2 Procedures for the Study

The first phase of the project was concerned essentially with obtaining, compiling, and presenting statistical and technical information about the industry and about the pollution emission control practices in it. Information was gathered on the locations, types and capacities of all aluminum reduction plants in the United States. Cooperation among the producers was obtained in supplying available control information in these plants to assist in evaluation of industry practice by erection of models representative of industry segments.

Projections of historical and statistical data were made in an attempt to present a picture of future growth, and technological modifications.

A second phase of the study involved the analysis and reduction of this information to forms which were used in a systems analysis of emissions control technology in the industry. By appropriate modeling based on confirmed flow diagrams, the cost and effectiveness of emission control were evaluated for individual sources and for the entire reduction process. New foreign and domestic developments were considered in addition to current United States practices.

Based upon all of the preceding work, recommendations were made as to useful research and development efforts. The recommendations fall into the following general areas of investigation:

a) Improvement in effluent hooding or collection systems,

b) Reduction of effluents from the Hall-Heroult alumina reduction process,

c) Improvement in the performance of existing control equipment,

d) Fundamental research in pollution abatement technology, A final part of the work was an economic study of emission control in the primary aluminum industry. A model was developed which utilizes the information gathered in previous phases to make possible estimates of the capital costs and annual operating and maintenance costs of pollution control equipment now in operation in the industry. A projection model was developed to provide the capability of projecting expenditures for achieving desired higher levels of emission control for a reasonable time into the future.

1.3 Data Base

Data in five related areas of knowledge were collected through three principal activities. The five data categories are:

a) Production Statistics - Determination of past, present, and probable future aluminum production at all present and projected smelter sites in the United States.

b) Process Technology - Description of the technology of aluminum smelting and of the associated effluents production and control.

c) Control Equipment - Description and evaluation of equipment and techniques available for emission control in the aluminum industry.

d) Air Pollution - Determination of quantitative and qualitative aspects of emissions attributable to aluminum smelters.

e) Projections - Construction of models for future aluminum production and the needs for emission control.

A data base in these five areas was developed through three coordinated activities:

a) Literature Search - Extraction from the technical literature of data pertaining to the handling of fluorides and to all emission control in the primary aluminum industry.

b) Smelter Industry Questionnaire - Collection of data from primary aluminum producers through a comprehensive formal questionnaire.

c) Contact and Communication - Personal and correspondence contacts with aluminum producers and pollution control equipment manufacturers, to enlarge the data base and to improve understanding of the problems and technologies of emission control in the primary aluminum industry.

These data were correlated and analyzed in preparation for Phase II, the evaluation of current and future cost effectiveness and the identification and analysis of research and development projects in the field of emission control technology.

1.3.1 Technical Literature Sources

Searches through the technical literature disclosed several hundred references which relate to aluminum smelting and the control of associated pollutant emissions. Of particular value in these searches were several index and abstracting services, especially:

Engineering Index
Aluminum Abstracts
Air Pollution Control Association Abstracts
Chemical Abstracts
Air Pollution Technical Information Center
of the Environmental Protection Agency

In addition, an earlier study for Environmental Protection Agency, "Control Techniques for Fluoride Air Pollutants", provided more than one hundred useful reference articles.

1.3.2 Industry Questionnaire

Through the assistance and cooperation of the Primary Aluminum Industry Liaison Committee representing all aluminum producing companies in the United States, a comprehensive questionnaire was developed which sought to bring together all available plant data on aluminum smelting effluents and their control. Appendix 1-A is a condensed example of this questionnaire. Responses to this questionnaire were prepared by most United States companies representing the current status of air pollution control at 30 primary smelters, located in 16 states and ranging in individual plant production capacity from approximately 35,000 short tons to 275,000 short tons of aluminum per year. No company could answer all the questions but the composite represents a fair picture of the effluents and diverse methods of control practiced in the United States.

1.3.3 Industry Contacts

To better interpret the data and to better understand the problems of controlling aluminum smelter effluents, teams of engineers visited nearly all of the American smelters to see control measures in operation and to discuss the technology of pollution control with the plant operating personnel directly involved with the problems.

1.3.4 Equipment Suppliers

Based on an analysis of the different types of control equipment applicable to the various components of reduction plant effluents, technical and cost information was obtained concerning such equipment by direct contact with representative suppliers. These data were correlated, where possible, with information contained in industry questionnaire response. Comparative costs, performance characteristics, and claimed efficiencies were obtained among the equipment types currently available to the industry.

Contacts were also made to gain an insight into the current trends of manufacturers development activities leading to future improvements and changes.

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2.0 The Primary Aluminum Industry

2.1 Background

Aluminum is the most abundant metallic element in the earth's crust. Its supply potential is limited only by the technology and economics of extraction, which currently restrict the commercial raw material to bauxite ore, although recent announcements have been made by the USSR of a major project utilizing nephelite, an ore with a lower aluminum content than bauxite. According to the Russians, this economic disadvantage can be overcome by a marketable by-product yield of cement, soda, and potash. Poland and Mexico are reported to be seriously considering processing non-bauxite aluminum ores. Poland is reported to be constructing plants for obtaining aluminum from clays. Developmental work on this approach has been carried out in the United States and technical feasibility demonstrated, but economics are unfavorable as compared to the use of bauxite. Mexican researchers have announced the successful development of a process for treating alunite ores containing relatively low (10%) content of alumina. Like nephelite treatment, the economics are concerned with the marketability of co-products, in this case potassium and ammonium sulfate fertilizers.

Bauxite ores are plentiful, although the principal deposits are located in tropical areas away from the main aluminum metal producing and consuming centers of North America, Europe and Japan. Known reserves are constantly being expanded by geological exploration and discoveries; the largest are located in Australia, Guinea, Jamaica, and Surinam. The reserves of commercial bauxite in the United States are relatively small, and account for less than 1% of the world total.

Bauxite is converted to the intermediate refined product, alumina, by extraction with caustic soda, precipitation of purified aluminum hydrate, and calcination. This Bayer process treatment is used almost universally throughout the world, although in Norway a small tonnage of alumina is extracted commercially from high-iron bauxite by the Pedersen smelting process in which bauxite, limestone, and coke are smelted in an electric furnace to produce pig iron and calcium aluminate slag containing 30-50% alumina. The slag is leached with sodium carbonate solution and the aluminum trihydrate is precipitated with carbon dioxide.

Alumina is the principal feed material for the production of aluminum metal by electrolytic reduction. In its commercial form it is a fine white powder, 40 mesh to submicron in particle size, with about 0.5% impurities, principally soda (Na_2O), with minor contamination of calcium oxide, silica, and iron oxide. About one ton of alumina is produced from two tons of bauxite.

The economics of shipping costs, combined with political considerations, have resulted in the location of many alumina plants at sites closer to the mining operations than to the reduction plants.

2.1.1 Power

Electric power (7.2 kwh per pound of metal) is, after cost of alumina, the largest cost item in the production of aluminum metal, and its availability and cost has historically been a determinant factor in smelter location.

The early plants in the United States and Canada were based on cheap hydroelectric power from Niagara Falls and the upper St. Lawrence River, and later in North Carolina and Tennessee. Development of hydroelectric power in the Northwest by Bonneville Power Authority attracted reduction plants to Oregon and Washington.

In the early 1950's with most of the available low cost hydropower in the Northeast, Southeast, and Northwest developed, there was a move to other sources of power. The Gulf Coast offered natural gas, and attracted major plants in Texas. One Texas plant was based on lignite coal.

Development of large fossil fuel generating stations in the Ohio River Valley, some of them located at mine mouth, resulted in power costs which, although higher than those from hydro, were low enough to draw new reduction plants. In the Tennessee Valley Authority area, as well as in the Pacific Northwest, fossil fuel stations have supplemented hydro in the power distribution systems. Nuclear power stations are being built within these systems for the same purpose.

2.1.2 Alumina Shipments

Aside from the considerations of low cost power, another important factor in plant location has been accessibility to cheap water-borne transportation for raw materials, especially alumina from domestic and overseas plants. With the exception of three, domestic reduction plants built since 1950 have been on waterways navigable by ship or barge. The exceptions have been able, by special circumstances, to obtain sufficiently attractive trans-shipment and rail facilities to compensate.

2.1.3 Marketing Areas

The relative location of reduction plants to marketing areas for primary metal has not, in the past, been a major determinant in plant location, being overbalanced by the pressure to obtain low cost power. As the latter has become increasingly scarce, transportation cost of metal has assumed a greater importance, and has acted to shift reduction facilities closer to markets, both those for semi-fabricated forms of metal and those for finished end product.

2.1.4 International Integration of the Aluminum Industry

About 80% of the free world productive capacity for bauxite, alumina, and aluminum is operated by some six corporate groups, or their subsidiaries or affiliates. All are fully integrated from the mining of bauxite through to the production of semi-finished and finished aluminum products. They are involved, jointly or with other firms, in virtually all major aluminum projects of international significance in the free world.

Somewhat more than 10% of the current free world primary metal capacity is accounted for by producers in which a majority interest is held by the respective national governments as partner with major aluminum producers. Somewhat less than 10% of free world capacity is in the hands of smaller organizations whose integration extends only towards semi-finished products.

This internationalization and vertical integration of the industry has developed by reason of the geographical distribution of ore reserves with respect to low cost power and to markets, and because of the very large capital investments required by the economic scale of operations, particularly in mining and alumina refining.

Increasing costs, both capital and production, in the past twenty-five years have led to a shift in the economic center of gravity away from markets towards raw materials. As a result, the trend is toward location of primary metal reduction plants nearer the sources of bauxite, or at best, to areas where cost of product shipment and marketing is more than offset by lower cost power, and/or savings in material transport.

2.2 Production Statistics

Primary aluminum is defined as the commercially pure metal containing about 99.5% aluminum produced usually by the electrolytic reduction of alumina and cast in the form of ingot, slab or billet for subsequent working into semi-fabricated shapes or finished products.

2.2.1 World Production

The estimated world production of primary metal in 1969 was 10,019 thousand short tons 1/. Primary aluminum was produced in 33 countries, with the United States accounting for 37.9% of the world output. Seven other countries, (the USSR, Canada, Japan, Norway, France, West Germany, and Italy) produced 43.5% of the world output. Table 2.1 presents world production statistics over the period 1960-1969 which illustrate the industry growth increase over this period.

2.2.2 Domestic Production

Production of primary aluminum metal in the United States was begun in 1858, and data on production starts in 1893, covering the industry from its very early period. The semi-log graph, Figure 2.1, illustrates the rapid growth of the domestic primary industry from 1893, and Table 2.2 gives the actual production figures. The average rate of growth since 1893 has been 14.8% and since 1946, 10.2%.

1/ Aluminum Association

Table 2.1 WORLD PRODUCTION OF PRIMARY ALUMINUM, 1960 - 1969

Thousands of short tons

COUNTRY	1969p	1968r	1967r	1966	1965	1964	1963	1962	1961	1960
WORLD TOTAL(1)	10,019	8,876r	8,343r	7,583	6,951	6,553	5,862	5,580	5,185	4,950
NORTH AMERICA - Total	4,927	4,265	4,268	3,881	3,606	3,415	3,038	2,808	2,567	2,777
Canada	1,098	985	975	890	831	843	719	690	663	762
United States	3,793	3,255	3,269	2,968	2,754	2,553	2,313	2,118	1,904	2,014
Mexico	36	25	24	22	21	19	6	-	-	-
SOUTH AMERICA - Total	121	105	79r	58	35	29	19	22	22	20
Brazil	48	46	42r	30	34	29	19	22	22	20
Surinam	59	48	34	28	1	-	-	-	-	-
Venezuela	15	11	3	-	-	-	-	-	-	-
ASIA - Total(1)	935	786	632r	593	529	487	431	350	310	264
China(1)	132	99	88r	110	110	110	110	110	110	88
India	145	132	106	92	74	62	61	39	20	20
Japan	627	532	421	372	324	293	247	189	169	147
South Korea	7	-	-	-	-	-	-	-	-	-
Taiwan	24	22	17	19	21	21	13	12	10	9
AFRICA - Total	176	170	97	54	56	57	58	58	52	48
Cameroon	52	50	53	54	56	57	58	58	52	48
Ghana	125	120	44	-	-	-	-	-	-	-
OCEANIA - Australia	139	107	102	101	97	88	46	18	15	13

r - Revised
p - Preliminary
(1) Estimated by the Bureau of Mines, Department of Interior.

Detail may not add to totals due to rounding.

SOURCE: U.S. Department of the Interior, Bureau of Mines,
as reported by the Aluminum Association, 1969.

Table 2.1 WORLD PRODUCTION OF PRIMARY ALUMINUM, 1960 - 1969 (Cont.)

Thousands of short tons

COUNTRY	1969p	1968r	1967r	1966	1965	1964	1963	1962	1961	1960
EUROPE - TOTAL(1)	3,720	3,444r	3,164r	2,897	2,629	2,477	2,269	2,325	2,220	1,827
Common Market Countries - Total	937	892	853	833	770	718	660	613	590	541
France	409	403	398	401	375	348	329	325	308	263
Germany, West	290	278	279	269	258	242	230	196	190	186
Italy	159	157	141	141	137	127	101	91	92	92
Netherlands	79	54	35	22	-	-	-	-	-	-
European Free Trade Association - Total	865	799r	645	592	540	513	452	419	364	350
Austria	106	95	87	87	87	86	84	82	75	75
Norway	564	516r	398	357	304	288	248	227	189	182
Sweden	74	62	38	32	35	34	19	18	17	18
Switzerland	85	85	80	76	74	71	66	55	47	44
United Kingdom	37	42	43	41	40	36	34	38	36	32
Other - Total(1)	1,918	1,753r	1,666r	1,472	1,319	1,245	1,157	1,293	1,266	936
Czechoslovakia(1)	72	72	72	68	68	65	65	65	55	44
Germany, East(1)	88	88	88	88	77	72	50	50	50	44
Greece	88	84	79	40	-	-	-	-	-	-
Hungary	71	69	68	67	64	63	61	58	56	55
Iceland	14	-	-	-	-	-	-	-	-	-
Poland (includes secondary)	107	103	102	61	52	53	51	53	52	29
Rumania (includes secondary)	99	84	58	52	25	-	-	-	-	-
Spain	114	98r	86r	70	57	55	50	46	42	32
U.S.S.R.(1)	1,213	1,102r	1,064	980	930	900	840	990	980	705
Yugoslavia	53	53	49	46	46	38	40	31	30	28

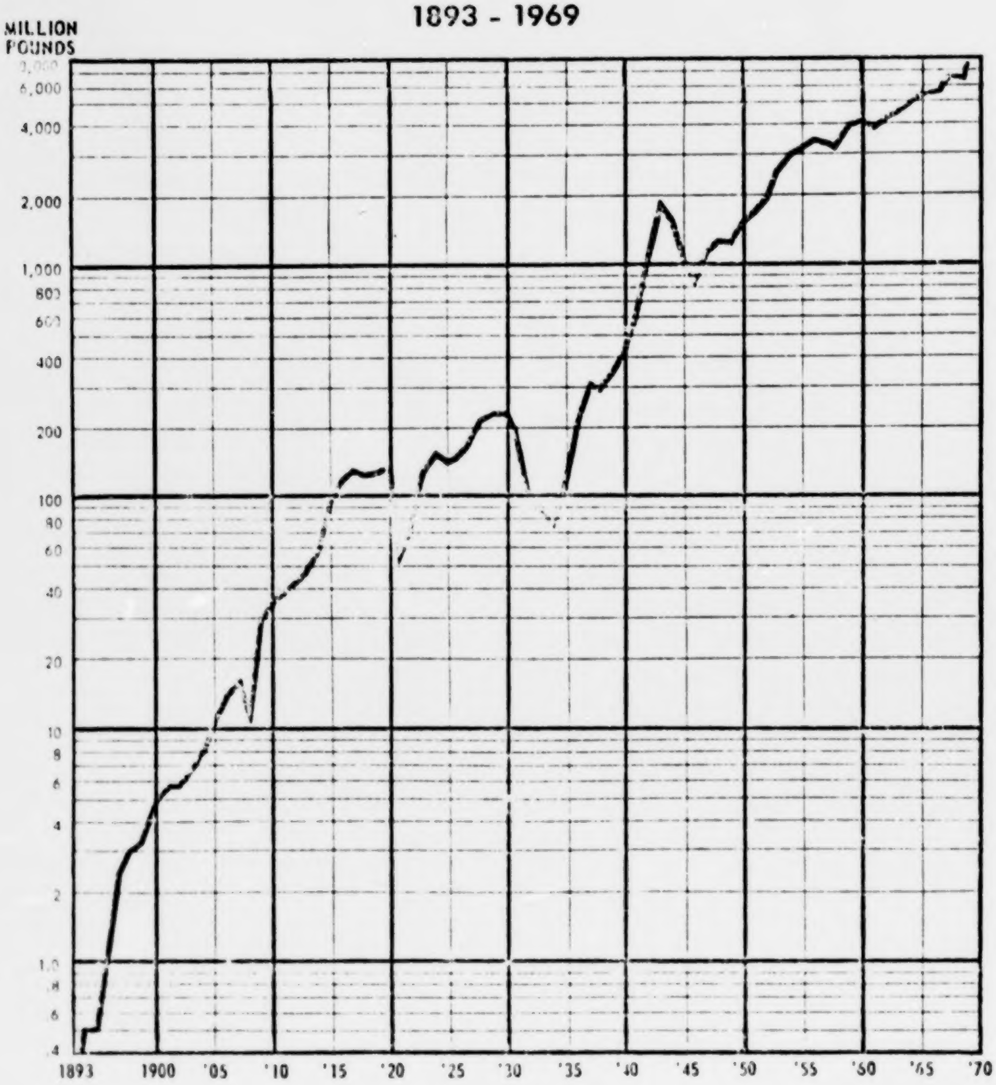
r - Revised
p - Preliminary
(1) Estimated by the Bureau of Mines, Department of Interior.

Detail may not add to totals due to rounding.

SOURCE: U.S. Department of the Interior, Bureau of Mines, as reported by the Aluminum Association, 1969.

Figure 2.1

Primary Aluminum Production in the United States 1893 - 1969



SOURCE: The Aluminum Association

Table 2.2

PRODUCTION OF PRIMARY ALUMINUM IN THE UNITED STATES

Year	Millions of Pounds	Year	Millions of Pounds	Year	Millions of Pounds	Year	Millions of Pounds
		1911	38.4	1931	177.5	1951	1,673.8
		1912	41.8	1932	104.9	1952	1,874.7
1893	0.2	1913	47.3	1933	85.1	1953	2,504.0
1894	0.5	1914	58.0	1934	74.2	1954	2,921.1
1895	0.5	1915	90.5	1935	119.3	1955	3,131.4
1896	1.0	1916	115.1	1936	224.9	1956	3,357.9
1897	2.4	1917	129.9	1937	292.7	1957	3,295.4
1898	3.0	1918	124.7	1938	286.9	1958	3,131.1
1899	3.3	1919	128.5	1939	327.1	1959	3,908.2
1900	5.1	1920	138.0	1940	412.6	1960	4,029.0
1901	5.8	1921	54.5	1941	618.1	1961	3,807.4
1902	5.8	1922	73.6	1942	1,042.2	1962	4,235.9
1903	6.6	1923	128.5	1943	1,840.4	1963	4,625.1
1904	8.1	1924	150.6	1944	1,552.9	1964	5,105.5
1905	10.8	1925	140.1	1945	990.1	1965	5,509.0
1906(1)	14.1	1926	147.4	1946	819.3	1966	5,936.7
1907	16.3	1927	163.6	1947	1,143.5	1967	6,538.5
1908	10.7	1928	210.5	1948	1,246.9	1968	6,510.1
1909	29.1	1929	228.0	1949	1,206.9	1969	7,586.1
1910	35.4	1930	229.0	1950	1,437.2	1970	7,942.0

(1) Data prior to 1907 represent years ending August 31. Production during last four months of 1906 totaled 5.4 million pounds.

SOURCES: U.S. Department of the Interior, Bureau of Mines and The Aluminum Association.

Reference: Aluminum Statistics - 1969, The Aluminum Association.

In the United States, the Aluminum Company of America (Alcoa) was the only domestic producer from 1886 to 1940. Under the impetus of World War II the domestic aluminum production was sharply increased, and by 1946 Reynolds Metals Company and Kaiser Aluminum & Chemical Corporation had become operators of reduction plants. Anaconda Aluminum Company began producing in 1954, and in 1958 Harvey Aluminum, Inc., and Ormet Corporation (a subsidiary of Olin Mathieson Chemical Corporation and Revere Copper & Brass, Inc.) entered the field. Consolidated Aluminum Corporation (now jointly owned by Phelps Dodge and Swiss Aluminum Ltd.) began production in 1963. Intalco Aluminum Corporation, owned 50% by American Metal Climax, Inc., and 25% each by a U.S. subsidiary of Pechiney (France) and by Howmet Corporation, started production of primary metal in 1966. National Southwire Aluminum, a partnership between Southwire (a fabricator) and National Steel Company, began operations in 1970, as did Revere Aluminum in their own plant and Eastalco, a partnership of Howmet and Pechiney.

In addition to these producers, two more, Noranda and Gulf Coast Aluminum, had reduction plants under construction at the end of 1970.

2.3 Primary Aluminum Capacity

The capacity ratings given to primary aluminum reduction plants are design capacities, and are nominal rather than exact. They are rates which are below the level at which a plant can actually produce by making (temporary) operational changes, perhaps at the expense of optimum electrometallurgical efficiency. While occasions for production exceeding design capacity have existed, the industry prefers to operate normally at, or somewhat below, capacity.

The consequent uncertainty in determination of an actual production capacity for an individual plant is compounded when the attempt is made to assess industry production capacities. Estimates are understood to represent nominal industry capability, rather than maximum potential.

2.3.1 World Capacity

Plant-by-plant compilations of primary aluminum capacities in the free world have been made and presented by the technical press which represent perhaps the best detailed analysis of the worldwide industry. One of the most recent was published by Metals Week, in "Aluminum - A Profile of an Industry", and is shown in Table 2.3 to illustrate the international character and interrelationships of the industry elements, as well as to give an approximate estimate of world primary aluminum capacity.

Based on the information from this source the current (1970) world distribution of primary aluminum capacity is:

Area Free World	1000 S.T. Annual Capacity		Percent	
North America	5,352		46.6	
Europe	2,281		19.9	
Asia	1,004		8.7	
Latin America	250		2.2	
Africa	231		2.0	
Oceania	209		1.8	
Subtotal, Free World		9,327		81.2
Sino-Soviet Block		2,161		18.8
World Total		11,488		100.0

A survey of announced plans for capacity growth within the free world was published by Metals Week (March 23, 1970) and illustrates the spreading international growth pattern of the industry. Tables 2.4a and 2.4b analyze the anticipated growth in terms of geographical expansion and numbers of producers in the free world.

Of the 30 new producers expected to enter the industry between 1969 and 1974, all except four are located outside of the continental United States. Of the 227 expansions of existing or proposed plants indicated in this forecast, only 32 are anticipated by U.S. producers.

In terms of distribution of capacity growth, the United States is expected to account for about 24%, divided almost equally between new plant capacity and expansion of

Table 2.3 FREE WORLD PRIMARY ALUMINUM CAPACITY AND OWNERSHIP

(Estimated Capacities in 1000 Short Tons at End of Year)

						Expansions		
COUNTRY	OWNERSHIP	1966	1967	1968	1969	1970	1971	1972
NORTH AMERICA								
Canada:								
Alcan Aluminium Ltd. (Alcan)		900	950	970	970	1,000	1,000	1,000
Canadian British Aluminium Co. Ltd. (CBA)	Reynolds Metals 83.5%	100	100	115	115	145	175	175
		1,000	1,050	1,085	1,085	1,145	1,175	1,175
United States: (See Table 2.5 for breakdown)		3,183	3,339	3,602	3,787	4,207	4,754	5,134
Total North America		4,183	4,389	4,687	4,872	5,352	5,929	6,309
LATIN AMERICA								
Brazil:								
Aluminio Mina Gerais, S.A.	Alcan 100%	18	22	25	25	33	33	33
Companhia Brasileira de Aluminio (CBA)	Government Owned	22	34	34	34	55	55	55
Companhia Mineira de Aluminio S.A. (Alcominas)	Alcoa 50% Hanna Mining 24% Brazil 26%	-	-	-	-	27	27	27
		40	56	59	59	115	115	115
Mexico:								
Aluminio S.A. de C.V.	Alcoa 46% Mexicans 54%	22	22	33	33	33	44	44
Surinam:								
Surinam Aluminum Co. (Suraico)	Alcoa 100%	50	50	77	77	77	77	77
Venezuela:								
Aluminio del Caroni,S.A.(Alcasa)	Reynolds 50% Government 50%	-	11	11	11	25	25	25
Total Latin America		112	139	180	180	250	261	261

Table 2.3 FREE WORLD PRIMARY ALUMINUM CAPACITY AND OWNERSHIP (Cont.)

(Estimated Capacities in 1000 Short Tons at End of Year)

						Expansions		
COUNTRY	OWNERSHIP	1966	1967	1968	1969	1970	1971	1972
EUROPE								
Austria:								
Vereinigte Metallwerke Ranshofen-Berndorf AG (VMRB)	Government Owned	80	80	80	90	90	90	90
Salsburger Aluminium GmbH (SAG)	Alusuisse 100%	12	12	12	12	12	12	12
		92	92	92	102	102	102	102
France:								
Compagnie Pechiney (Pechiney)		314	316	316	316	316	316	316
Ugine-Kuhlmann (Ugine)		89	90	90	90	90	90	90
		403	406	406	406	406	406	406
West Germany:								
Aluminium-Huette Rheinfelden GmbH	Alusuisse 100%	61	66	69	69	69	69	69
Vereinigte Aluminium-Werke AG (VAW)	Government Owned	218	218	218	218	218	218	218
Leichmetall-Gemeinschaft	Alusuisse 50% Metallgesellschaft 50%	-	-	-	-	-	76	88
Gebruder Giulini, GmbH		-	-	-	22	22	22	22
		279	284	287	309	309	385	397
Greece:								
Aluminium de Grece S.A.	Pechiney 72% Ugine 18% Government 10%	69	80	83	86	86	86	86
Iceland:								
Icelandic Aluminum Co. Ltd. (Isal)	Alusuisse 100%	-	-	-	-	36	36	36

Table 2.3 FREE WORLD PRIMARY ALUMINUM CAPACITY AND OWNERSHIP (Cont.)

(Estimated Capacities in 1000 Short Tons at End of Year)

						Expansions		
COUNTRY	OWNERSHIP	1966	1967	1968	1969	1970	1971	1972
EUROPE (Cont.)								
Italy:								
Alcan Alluminio Italiano S.p.A.	Alcan 100%	6	6	6	6	6	6	6
Montecatini-Edison		88	88	93	100	100	102	102
Societe Alluminio Veneto per Azioni S.p.A. (SAVA)	Alusuisse 100%	55	63	63	64	64	64	64
Alluminio Sarda (Alsar)	EFIM (Govt) 52% Montecatini-Edison 24% Societe Generale de Belgique 24%	-	-	-	-	55	110	110
		149	157	162	170	225	282	282
Netherlands:								
Aluminium Delfzijl N.V. (Aldel)	Hoogovens 50% Alusuisse 33% Billiton 17%	33	36	78	78	99	99	99
Norway:								
A/S Aardal og Sunndal Verk (Aardal)	Government 50% Alcan 50%	216	220	285	285	285	285	285
Det Norske Nitrid A/S (DNN)	British Aluminium 50% Alcan 50%	32	32	40	40	40	45	45
Mosjoen Aluminiumverk A/S (Mosal)	Alcoa 50% Elektrokemisk 50%	68	68	95	95	95	95	95
Alnor A/S (Alnor)	Norsk Hydro 51% Harvey Aluminum 49%	-	85	93	95	100	100	120
Elektrokemisk Aluminium A/S	Alcoa 50% Elektrokemisk 50%	-	-	-	-	-	36	36
Soer-Norge Aluminium A/S (Soral)	Alusuisse 100%	63	63	63	64	64	64	64
		379	468	576	579	584	625	645

Table 2.3 FREE WORLD PRIMARY ALUMINUM CAPACITY AND OWNERSHIP (Cont.)

(Estimated Capacities in 1000 Short Tons at End of Year)

COUNTRY	OWNERSHIP	1966	1967	1968	1969	Expansion 1970	 1971	 1972
EUROPE (Cont.)								
Spain:								
Aluminio Espanol S.A. (Alumespa)	Pechiney major interest	10	10	14	14	14	14	14
Empresa Nacional de Aluminio S.A. (Endasa)	Government 75% SECEN 19% Banco de Bilbao 3%	46	46	53	71	83	83	83
Aluminio de Galicia (Alugasa)	Pechiney 50% Endasa 10%	28	36	36	36	36	36	36
		84	92	103	121	133	133	133
Sweden:								
A/B Svenska Aluminiumkompaniet (Sako)	Alcan 21% Svenska Metallwerken 79%	33	55	72	72	77	77	77
Switzerland:								
Swiss Aluminium Ltd. (Alusuisse)		70	71	72	72	72	72	72
Usine d'Aluminium Martigny SA	Giulini 100%	10	10	10	10	10	10	10
		80	81	82	82	82	82	82
United Kingdom:								
British Aluminium Co.Ltd. (Baco)	Tube Investments 49½% Reynolds Metals 48%	39	39	42	42	42	154	154
Rio Tinto-Zinc/British Insulated Callendars Cables Ltd.	Rio Tinto Zinc) 60% tentative BICC) Kaiser 40%	-	-	-	-	-	112	112
Alcan Aluminium (UK) Ltd.	Alcan 100%	-	-	-	-	-	67	67
		39	39	42	42	42	333	333
Yugoslavia:								
State Industry	Government Owned	54	54	54	54	100	100	220
Total Europe ---		1,694	1,844	2,037	2,101	2,281	2,746	2,898

Table 2.3 FREE WORLD PRIMARY ALUMINUM CAPACITY AND OWNERSHIP (Cont.)

(Estimated Capacities in 1000 Short Tons at End of Year)

						Expansion		
COUNTRY	OWNERSHIP	1966	1967	1968	1969	1970	1971	1972
AFRICA								
Angola								
Aluminio Portugues	Pechiney 8.6%	-	-	-	-	27	27	27
Cameroon:								
Alucam	Pechiney-Ugine 60% Cobeal 10%	57	57	57	57	57	57	57
Ghana:								
Volta Aluminum Corp. (Valco)	Kaiser Aluminum 90% Reynolds Aluminum 10%	-	115	115	115	115	160	160
South Africa:								
Aluminium South Africa (Alusaf)	Alusuisse 22% Government 78%	-	-	-	-	32	55	55
Total Africa		57	172	172	172	231	299	299
ASIA								
Bahrein:								
Aluminium Bahrein (Alba)	Bahrein Government 27½% British Metal Corp. 25% Akiebolaget Elektro-koppar 25% Western Metal Corp. 12½% Guiness Mahon 10%	-	-	-	-	-	88	88
INDIA:								
Aluminium Corp. of India Ltd. (Alucoin)		8	8	10	10	11	13	13
Indian Aluminium Co. Ltd. (Indal)	Alcan 65%	40	40	41	55	73	73	94
Hindustan Aluminium Corp. Ltd. (Hindalco)	Kaiser 27% Birla & Public 73%	53	66	66	66	66	77	110
Madras Aluminium Co.Ltd. (Malco)	Montecatini 27%	11	11	13	13	22	28	28
Bharat Aluminium	Government Owned	-	-	-	-	-	-	28
		112	125	130	144	172	191	273

Table 2.3 FREE WORLD PRIMARY ALUMINUM CAPACITY AND OWNERSHIP (Cont.)

(Estimated Capacities in 1000 Short Tons at End of Year

COUNTRY	OWNERSHIP	1966	1967	1968	1969	Expansion		
						1970	1971	1972
IRAN:								
Iran Aluminium Co.	Iran Government 65% Reynolds 25% Pakistan Government 10%	-	-	-	-	-	55	55
JAPAN:								
Nippon Light Metal Co. Ltd. (NLM)	Alcan 50%	140	162	184	184	245	311	311
Showa Denko K. K. (Showa)		85	100	155	175	175	317	317
Sumitomo Chemical Co. Ltd. (Sumitomo)		88	100	144	171	200	200	232
Mitsubishi Chemical Industries (Mitsubishi)		66	74	123	123	173	173	173
Mitsui Aluminium Co. (Mitsui)		-	-	-	-	-	41	83
		379	436	606	653	793	1,042	1,116
TAIWAN:								
Taiwan Aluminium Corp. (Taialco)	Government Owned	22	22	22	27	39	42	42
TURKEY:								
Government	Government Owned	-	-	-	-	-	-	66
Total Asia --		513	583	758	824	1,004	1,418	1,640

Table 2.3 FREE WORLD PRIMARY ALUMINUM CAPACITY AND OWNERSHIP (Cont.)

(Estimated Capacities in 1000 Short Tons at End of Year)

						Expansion		
COUNTRY	OWNERSHIP	1966	1967	1968	1969	1970	1971	1972
OCEANIA								
Australia:								
Alcoa of Australia Ltd.	Alcoa 51% Western Mining Corp. 20% Broken Hill South 17% North Broken Hill 12%	44	44	44	88	88	88	99
Comalco Industries Pty. Ltd. (Comalco)	Kaiser 50% Conzinc Riotinto 50%	62	81	81	81	81	81	81
Alcan Australia Ltd.	Alcan 100%	-	-	-	40	40	40	40
		106	125	125	209	209	209	220
New Zealand:								
Comalco/Sumitomo/Showa Denko	Comalco 50% Sumitomo 25% Showa Denko 25%	-	-	-	-	-	79	118
Total Oceania		106	125	125	209	209	288	338
GRAND TOTALS		6,665	7,252	7,959	8,358	9,327	10,941	11,745

Source: Farin and Reibsamen, "Aluminum, A Profile of an Industry," 1969

Table 2.4a SUMMARY OF ANTICIPATED CAPACITY GROWTH, 1969-1974

(Free World)

a) Capacity Units

	Producers			Expansions By	Producing Countries	
	Existing	New	Total	Existing Producers	New	Total
Mid-1968	51					23
-1969	51	5	56	39	2	25
-1970	56	3	59	40	-	25
-1971	59	14	73	46	4	29
-1972	73	4	77	50	2	31
-1973	77	3	80	29	1	32
-1974	80	1	81	23	1	33
1969-1974		30		329	10	

b) Distribution of Anticipated Growth, U. S. & Others (1969-1974)

	Estimated Metric Tons				Percentage of Capacity Increase		
	U. S.	Others	Total		U. S.	Others	Total
By Plant Expansion	737	1,289	2,026		12.7	22.2	34.9
In New Plants	634	3,135	3,769		11.0	54.1	65.1
Total Capacity Increase (1969-1974)	1,371	4,424	5,795	(82.7%)	23.7	76.3	100.0
Mid-1968 Estimated Capacity			6,988	(100.0%)			
Estimated 1974 Capacity			12,783	(182.7%)			

(Estimates published - Metals Week, March 23, 1970)

Table 2.4b SUMMARY OF ANTICIPATED CAPACITY GROWTH, 1969-1974

(Free World)

c) Patterns of World Capacity Expansion (1969-1974)

	Base 1969	Capacity Expansion 1974 By Plant Expansions	Capacity Expansion 1974 In New Plants	Total Capacity Increase
Est. Quantity, 1000 M.T.	7548	2026	3769	5795
Distribution		35%	65%	100%
Increase, % of 1969		27%	50%	77%
Pattern by Geographical Area (% of Free World)				
EEC[1]	11%	10%	22%	17%
EEC Associates[2]	3	4	1	2
EFTA[3]	11	16	12	13
Other Europe	2	5	3	5
Total Europe	27%	35%	38%	37%
North America	58	37	24	28
Latin America	2	4	4	4
Africa	2	3	2	2
Asia	19	17	28	25
Oceania	2	4	4	4
Total Free World	100%	100%	100%	100%

1/ European Economic Community (France, West Germany, Italy, Netherlands, Belgium-Luxembourg).

2/ Cameroon, Greece, Surinam, Turkey.

3/ United Kingdom, Austria, Norway, Sweden, Switzerland, Iceland.

SOURCE: Metals Week Roundup - March 23, 1970.

existing plants. The growth in the rest of the free world is anticipated to be more than three times that of the domestic industry, with 70% of that growth as new plant capacity.

2.3.2 Domestic Capacity

As of December 31, 1948 there were three domestic producers of primary aluminum in the United States with a combined annual capacity of 641,500 short tons. Capacity increases were frequent through 1959, when total annual capacity stood at 2,402,750 short tons at year end, and three new producers had entered the field.

During the next five years through 1964, total annual capacity increased only 8.2% and only one new producer appeared. During the four years, 1965 through 1968, capacity increased 49.6%, an average annual rate of 8.4%.

During 1969 capacity increased 203,300 short tons to 3,888,300 short tons, a gain of 5.5% over 1968. This is compared to an expansion of 11.0% in the previous year. A ninth primary producer came on-stream in 1969.

Table 2.5 shows the reported annual capacities of the producers during the period 1948-1969.

Six of the existing producers have announced plans for additional capacity or modernization in the period 1970-1972. Four new producers have new plants under construction at the start of 1970, and a fifth new producer appears to be a probability in the next three years.

Table 2.6 lists the individual production plants in operation, or under construction in 1970, with the data indicating their capacity increases during the 1966-1972 period. It is noted that the capacities given in this table do not exactly coincide with totals presented for companies in Table 2.5. The estimates are from different, but equally authoritative sources and the differences are considered to be not significant.

The amount of excess domestic capacity in relation to production which has existed in the past two decades is indicated in Figure 2.2 from data given in Table 2.7. Capacity increase approximately matched that of production

Table 2.5 REPORTED CAPACITIES OF PRIMARY ALUMINUM PRODUCERS, 1948 - 1969

1948 - 1969
Short Tons

Year(1)	Total	Alcoa	Reynolds	Kaiser	Intalco	Ormet	Anaconda	Consolidated	Harvey	National-Southwire
1948	641,500	325,000	188,000	128,500	-	-	-	-	-	-
1949	654,000	294,000	227,000	133,000	-	-	-	-	-	-
1950	751,250	369,750	238,500	143,000	-	-	-	-	-	-
1951	800,750	371,250	259,500	170,000	-	-	-	-	-	-
1952	1,155,700	484,250	353,250	318,200	-	-	-	-	-	-
1953	1,335,700	548,000	359,500	428,200	-	-	-	-	-	-
1954	1,413,200	570,500	414,500	428,200	-	-	-	-	-	-
1955	1,634,700	706,500	440,000	428,200	-	-	60,000	-	-	-
1956	1,775,500	792,500	488,500	434,500	-	-	60,000	-	-	-
1957	1,839,000	792,500	488,500	498,000	-	-	60,000	-	-	-
1958	2,194,250	798,250	601,000	537,000	-	144,000	60,000	-	54,000	-
1959	2,402,750	798,250	701,000	609,500	-	180,000	60,000	-	54,000	-
1960	2,468,750	853,250	701,000	609,500	-	180,000	65,000	-	60,000	-
1961	2,483,750	853,250	701,000	609,500	-	180,000	65,000	-	75,000	-
1962	2,488,750	853,250	701,000	609,500	-	180,000	65,000	-	80,000	-
1963	2,510,750	853,250	701,000	609,500	-	180,000	67,000	20,000	80,000	-
1964	2,599,100	858,100	725,000	650,000	-	180,000	67,000	32,000	87,000	-
1965	2,758,284	950,000	725,000	650,000	-	184,284	100,000	62,000	87,000	-
1966	3,165,284	1,050,000	815,000	670,000	152,000	184,284	100,000	106,000	88,000	-
1967	3,321,000	1,150,000	815,000	670,000	152,000	240,000	100,000	106,000	88,000	-
1968	3,686,000	1,200,000	895,000	690,000	255,000	240,000	175,000	140,000	91,000	-
1969	3,888,300	1,325,000	935,000	710,000	265,000	240,000	175,000	140,000	91,000	7,300

(1) Capacities shown are as reported for December 31.

SOURCE: The Aluminum Association.

Table 2.6

INDIVIDUAL ALUMINUM SMELTER CAPACITIES

(Thousands of Short Tons at Year End)

EXISTING COMPANIES	1966	1967	1968	1969	1970	1971	1972
Alcoa:							
Alcoa, Tenn.[1]	125	125	125	200	200	NA	NA
Badin, N.C.	50	100	100	100	100		
Evansville, Ind.	175	175	175	175	225		
Massena, N.Y.	125	125	125	125	125		
Point Comfort, Tex.[2]	175	175	175	175	175		
Rockdale, Tex.	175	175	175	225	275		
Vancouver, Wash.	100	100	100	100	100		
Wenatchee, Wash.	125	175	175	175	175		
Alcoa Total	1,050	1,150	1,150	1,275	1,375	1,425	1,475e
Anaconda:							
Columbia Falls, Mont.[2]	105	105	175	175	175	175	175
Sebree, Ky.	-	-	-	-	-	-	50e
Anaconda Total	105	105	175	175	175	175	225e
Conalco:							
New Johnsonville, Tenn.	106	106	140	140	140	140	140
Harvey:							
The Dalles, Ore.[2]	88	88	88	88	88	88	88
Near John Day Dam in southern Washington[2]	-	-	-	-	-	100	100
Harvey Total	88	88	88	88	88	188	188
Intalco:							
Ferndale, Wash.	165	165	264	264	264	264	264
Kaiser:							
Chalmette, La.[3]	260	260	260	260	260	NA	NA
Mead, Wash.	206	206	206	206	206		
Ravenswood, W.Va.	163	163	163	163	163		
Tacoma, Wash.[4]	41	41	61	81	81		
Kaiser Total	670	670	690	710	710	740e	770e
Ormet:							
Hannibal, Ohio	184	240	240	240	240	240	240

Table 2.6 (Cont.)

INDIVIDUAL ALUMINUM SMELTER CAPACITIES

(Thousands of Short Tons at Year End)

EXISTING COMPANIES	1966	1967	1968	1969	1970	1971	1972
Reynolds:							
Arkadelphia, Ark.4/	63	63	63	63	63	NA	NA
Corpus Christi, Tex.3/	111	111	111	111	111		
Jones Mills, Ark.	122	122	122	122	122		
Sheffield, Ala.3/	221	221	221	221	221		
Longview, Wash.3/	70	70	110	150	190		
Massena, N.Y.3/	128	128	128	128	128		
Troutdale, Ore.	100	100	100	100	140		
Reynolds Total	815	815	855	895	975	1,005e	1,065e
Total Existing Companies	3,183	3,339	3,602	3,787	3,967	4,177e	4,367e
NEW COMPANIES							
Eastalco:							
Frederick, Md.	-	-	-	-	85	85	170
Gulf Coast Aluminum:							
Lake Charles, La.	-	-	-	-	-	35	35
National-Southwire Aluminum:							
Hawesville, Ky.	-	-	-	-	90	180	180
Noranda:							
New Madrid, Mo.	-	-	-	-	-	75	75
Revere:							
Scottsboro, Ala.	-	-	-	-	-	72	112
Total New Companies	-	-	-	-	175	447	572
Grand Total	3,183	3,339	3,602	3,787	4,142	4,624e	4,939e

NA——not available
e——METALS WEEK estimates

SOURCE: Farin and Reibsamen, "Aluminum, A Profile of an Industry," 1969

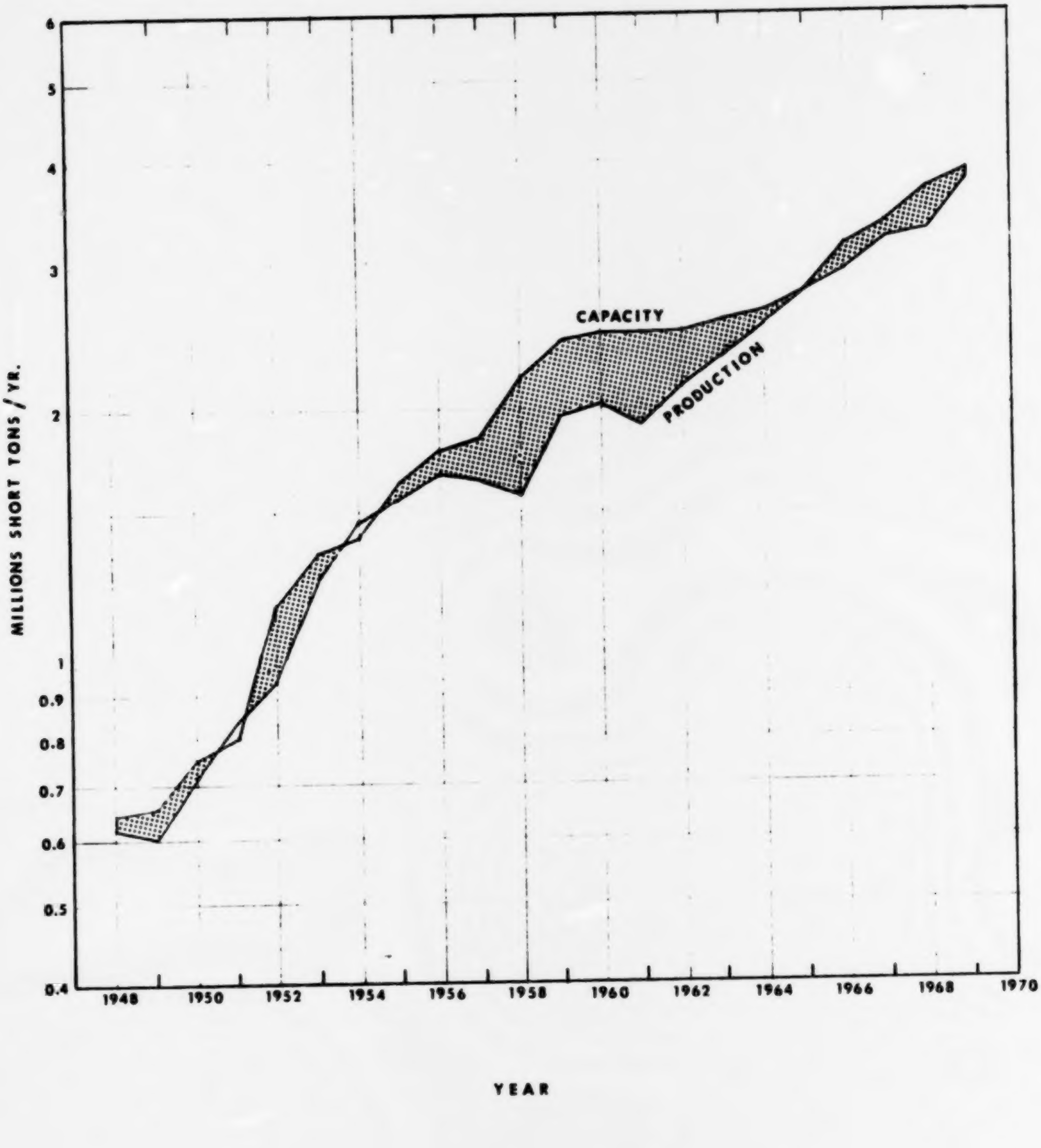
Note: All plants prebaked anode cell except:

1/ Both prebake and VSS potlines
2/ VSS potlines only
3/ HSS potlines only
4/ Both prebake and HSS potlines

FIGURE 2.2

EXCESS CAPACITY

U.S. PRIMARY ALUMINUM INDUSTRY



DATA SOURCE: ALUMINUM STATISTICS, 1969 THE ALUMINUM ASSOCIATION

Table 2.7

U. S. CAPACITY vs. PRODUCTION (See Fig. 2.3)

	1000 Tons			
	Rated Cap.[1]	Production[1]	Prod./Cap. %	Cap./Prod. %
1948	641.5	623.5	97	103
1949	654	603.5	92.5	108
1950	751	718.6	95.5	104.5
1951	800.7	836.9	104.5	96
1952	1155	937.4	81.2	123
1953	1336	1252.0	94.0	106
1954	1413	1460.5	103.0	97
1955	1635	1565.7	95.6	103.5
1956	1776	1679.0	94.6	105.5
1957	1839	1647.7	89.7	111
1958	2194	1565.5	71.2	140
1959	2408	1954.1	81.3	123
1960	2469	2014.5	83.5	120
1961	2484	1903.7	76.5	130
1962	2488	2118.0	85.0	126
1963	2511	2312.0	92.0	109
1964	2599	2553.0	98.0	102
1965	2758	2754.5	100.0	100
1966	3165	2968.4	93.8	107
1967	3321	3269.0	98.5	102
1968	3666	3255.0	89.0	112
1969	3888	3798.0	97.6	102

1/ Source: Aluminum Statistics - 1969, The Aluminum Association.

during 1948-1956 and a narrow margin (approximately 5%) of excess maintained. A falloff in production in 1956-1958, coupled with the completion of scheduled capacity increases during 1956-1959, resulted in a period of some five years during which the excess capacity margin rose as much as 40% and averaged about 25%. The recovery of demand and production, coupled with a sharply reduced rate of capacity increase between 1960-1964, rapidly closed the gap to 5% (average) and restored what might be considered a normal relationship. Resumption of capacity increase after 1966 maintained this balance.

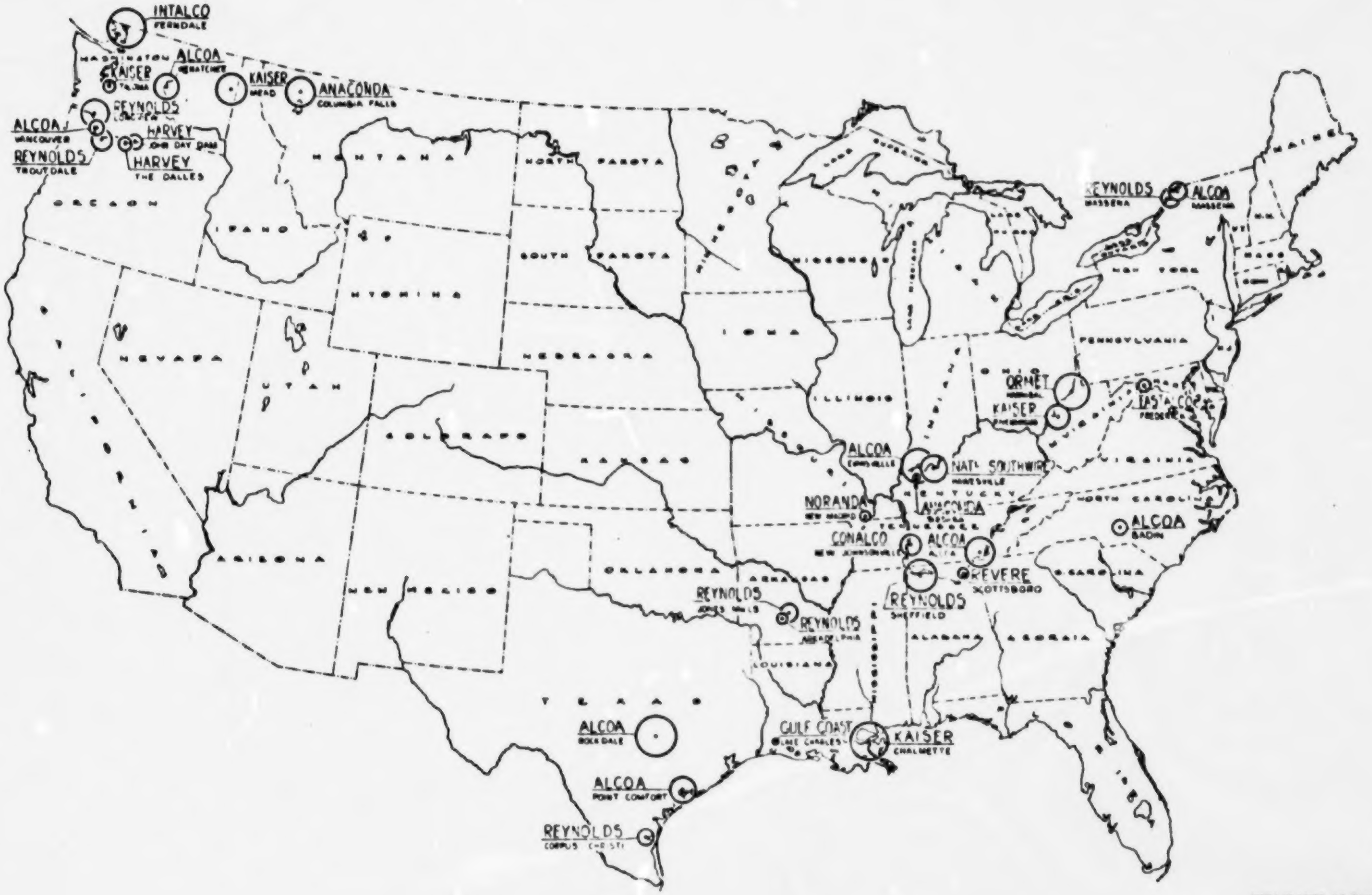
With the completion of the announced new plants and expansions in the period 1971-72 it appears likely that, in the short range, domestic capacity will again exceed domestic production by a significant amount.

During the last half of 1970 and the first half of 1971 the economic conditions in the aluminum industry have caused many producers, both domestic and foreign, to cut back production substantially from existing facilities, to stretch out construction schedules on new facilities, and to postpone announced plans for expansions. United States primary production in 1970 increased less than 5% over 1969 output, and 1971 may well show a decrease over 1970. The excess capacity gap in 1971-72 may be of the order of 20%, which has been exceeded in several previous years, and is a situation which gives the industry concern, for the short term, but not alarm in considering the longer view.

2.4 Domestic Plant Location

Figure 2.3 shows the geographical distribution of United States smelters and graphically indicates their relative current normal capacities by the size of the symbol at each location.

In addition to those listed, it appears quite possible that two more plants will be constructed by a new entrant into the United States primary aluminum industry. One of these would be located at Warrenton, Oregon on the site of the former Northwest Aluminum project, and the other in Puerto Rico. Firm announcement of these plants had not been made in 1970, and it is assumed that they would not come into production before 1973.


INTALCO
FERNDALE
WASHINGTON
ALCOA
WENATCHEE
KAISER
TACOMA
KAISER
MEAD
ANACONDA
COLUMBIA FALLS
REYNOLDS
LONGVIEW
ALCOA
VANCOUVER
HARVEY
JOHN DAY DAM
REYNOLDS
TROUTDALE
HARVEY
THE DALLES
OREGON
IDAHO
MONTANA
NORTH DAKOTA
SOUTH DAKOTA
WYOMING
NEVADA
UTAH
COLORADO
NEBRASKA
KANSAS
IOWA
ILLINOIS
ARIZONA
NEW MEXICO
OKLAHOMA
ARKANSAS
TEXAS
LOUISIANA
ALABAMA
GEORGIA
PENNSYLVANIA
NEW YORK
VIRGINIA
NORTH CAROLINA
KENTUCKY
TENNESSEE
OHIO
MAINE
ALCOA
ROCKDALE
ALCOA
POINT COMFORT
REYNOLDS
CORPUS CHRISTI
REYNOLDS
JONES MILLS
REYNOLDS
ARKADELPHIA
GULF COAST
LAKE CHARLES
KAISER
CHALMETTE
NORANDA
NEW MADRID
CONALCO
NEW JOHNSONVILLE
ALCOA
ALCOA
ANACONDA
SEBREE
ALCOA
NAT'L SOUTHWIRE
HAWESVILLE
REYNOLDS
SHEFFIELD
REVERE
SCOTTSBORO
ORMET
KAISER
EASTALCO
FREDERICK
ALCOA
BADIN
REYNOLDS
MASSENA
ALCOA
MASSENA

CIRCLE SCALE ——— EACH
DIVISION = APPROX. 40,000 TONS/YEAR.

FIGURE 2.3
ALUMINIUM SMELTERS
IN
UNITED STATES

NEW PLANTS AT PARTIAL CAPACITY IN 1970
EASTALCO - FREDERICK, MD
NATIONAL SOUTHWIRE - HOWESVILLE, KY
REVERE ALUMINUM - SCOTTSBORO, ALA

NEW PLANTS UNDER CONSTRUCTION IN 1970
ANACONDA - SEBREE KY
GULF COAST - LAKE CHARLES LA
HARVEY - JOHN DAY DAM, WASH
NORONDA - NEW MADRID MO

Most of the aluminum reduction plants in the United States are located in predominantly rural areas with a sparse population density, as estimated by the total population of towns or cities within a ten mile radius of each plant given in 1960 or later census figures.

The distribution of plants (1971) with respect to population is:

Number of Plants	Percent Capacity	Surrounding 300 Square Mile Area Population	Surrounding 300 Square Mile Area Population/Sq.Mi.
13	41.1	Less than 10,000	Less than 32
9	28.7	10-25,000	32-80
2	5.7	25-50,000	80-160
7	24.5	More than 50,000	More than 160

One plant is surrounded by residential sections in an urban community. The other six plants in the high density areas are located on the outskirts of medium sized communities where the surrounding land is utilized for dairy farming or truck farming.

The distribution of plant capacity with respect to the type of surrounding land use is shown in Table 2.8.

2.5 Peripheral Process Operations

Peripheral process operations are defined as those in-plant units, controlled by the reduction plant management and located on the reduction plant site, which supply power, steam, or materials to the reduction plant, or recover by-products from the plant.

Alumina production and/or coke calcining are usually carried out at locations which are remote from the aluminum production plant and they are not included in the scope of this study.

Power supply to reduction plants is generally purchased from utilities, some of which operate central stations largely dedicated to the reduction plant load. These stations, being independently operated by the utilities, are excluded from the scope of the study.

Table 2.8 ESTIMATED DISTRIBUTION OF PLANTS BY ENVIRONMENT

Environmental Category	Number of Plants	Percent of Total U. S. Aluminum Capacity in Environmental Category
Urban	1	5.5
Orchard Growing	4	15.4
Dairy Farming	3	9.4
Truck Farming	4	10.9
Cattle Raising	1	1.9
Lumbering	1	5.6
General Agriculture	2	2.4
Dairy plus Truck	2	6.3
Dairy plus Cattle	1	4.4
Dairy plus Agriculture	1	3.0
Dairy plus Lumber	1	1.7
Truck plus Cattle	1	3.0
Truck plus Lumber	4	11.3
Truck plus General Agriculture	1	3.5
Lumber plus General Agriculture	1	4.7
Truck Farming plus Cattle plus General Agriculture	3	11.0
Total	31	100.0

Source: Industry Questionnaires, EPA Contract CPA 70-21 and Encyclopedia Britannica.

In areas where cheap natural gas is available, five aluminum reduction plants have installed in-plant generation units incorporating gas engines, gas turbines, or gas-fired boiler steam turbine units. In two plants these installations are the normal power source, in another they are supplemented by purchased power, and in the remainder they supplement the power purchased from utilities.

Low Pressure Steam for process and heating requirements is generated at all plants, in almost all cases by gas-fired boilers.

Cryolite Recovery

Synthetic cryolite is produced from treatment of reclaimed pot materials in six plants which are part of primary reduction plant operations, as well as in another separate recovery plant operated by a major primary aluminum producer. Reclaimed pot materials from other reduction plants are generally shipped or sold to these cryolite plants on a toll basis.

Fluoride containing products of the water treatment from gas cleaning installations are generally impounded, although they may be recovered and treated with reclaimed pot materials where cryolite facilities are available. A few plants recover fluorine from this source alone.

The processing operations of cryolite recovery do not involve generation of airborne pollutants other than those incident to the crushing of feed and the final handling of calcined product. For this reason the reported questionnaire information covering these plants was scanty and in such form that it could not be meaningfully summarized with respect to industry operations or emissions from this source.

Table 2.9 indicates the peripheral process plant installations associated with domestic reduction plants, and Table 2.10 summarizes reported industry data concerning fired low pressure steam generation units.

Table 2.9 PERIPHERAL PLANT PROCESSES ASSOCIATED WITH U. S. PRIMARY ALUMINUM INDUSTRY, BY PLANTS, 1970

	Power	Cryolite Recovery Plant
Alcoa:		
Alcoa Tenn.	U	SH
Badin, N. C.	U	SH
Evansville, Ind.	U	SH
Massena, N. Y.	U	SH
Pt. Comfort, Tex.	P - U	SH
Rockdale, Tex.	U	SH
Vancouver, Wash.	U	SH
Wenatchee, Wash.	U	SH
Anaconda:		
Columbia Falls, Mont.	U	SL
Sebree, Ky.	U	SL
Conalco:		
New Johnsonville, Tenn.	U	SL
Harvey:		
The Dalles, Ore.	U	SL
John Day, Wash.	U	
Intalco:		
Ferndale, Wash.	U	SL
Kaiser:		
Chalmette, La.	U - P	R
Mead, Wash.	U	SL, R
Ravenswood, W.Va.	U	SL
Tacoma, Wash.	U	SL
Ormet:		
Hannibal, Ohio	U	R
Reynolds:		
Arkadelphia, Ark.	U	R
Corpus Christi, Tex.	P	R
Jones Mills, Ark.	U - P	SH
Sheffield, Ala.	U	R
Longview, Wash.	U	R
Massena, N. Y.	U	R
Troutdale, Ore.	U	R

Table 2.9 PERIPHERAL PLANT PROCESSES ASSOCIATED WITH U. S. PRIMARY ALUMINUM INDUSTRY, BY PLANTS, 1970 (Cont.)

	Power	Cryolite Recovery Plant
Eastalco:		
Frederick, Md.	U	R
Gulf Coast Aluminum:		
Lake Charles, La.	P	SL
National-Southwire Aluminum:		
Hawesville, Ky.	U	SL
Noranda:		
New Madrid, Mo.	U	SL
Revere:		
Scottsboro, Ala.	U	SL

Notes:

Power: U - Utility furnished.
P - In-plant generation by gas-fired units.

Cryolite: R - Recovery plant.
SH - Materials treated for recovery in parent company plant.
SL - Materials sold to other companies.

SOURCE: Industry Questionnaires and Plant Visits, EPA Contract CPA 70-21.

Table 2.10

PRIMARY ALUMINUM INDUSTRY; FIRED LOW PRESSURE STEAM GENERATION INSTALLATIONS, SUMMARY DATA

Total Units Reported	31
Normal Fuel - Natural Gas	30 units
Powdered Coal[1/]	1 unit
Emergency Back-up Fuel	
Residual Oil	5 units
Distillate	7 units
None	19 units
Normal Operating Time - 100%	17 units
50-100%	6 units
Less than 50%	8 units
Approx. Heating Rate - Maximum	117×10^6 BTU/Hr
Minimum	4×10^6 BTU/Hr
Average	30×10^6 BTU/Hr
Type of Boiler - Water Tube	19 units
Fire Tube	6 units
Direct or Indirect Heaters	6 units
Date of Installation (gas-fired)	1941-1970
Stack Heights	30-175 ft.

Region	Units	Heat Rate Range	Installations
Pacific Northwest	10	$4\text{-}56 \times 10^6$ BTU/Hr	1941-1968
Gulf Coast and Texas	3	$5\text{-}30 \times 10^6$ BTU/Hr	1952
TVA and Mississippi	8	$7\text{-}84 \times 10^6$ BTU/Hr	1942-1970
Eastern States	10	$5\text{-}117 \times 10^6$ BTU/Hr	1953-1970

[1/] Peak winter load only.

Source: Responses to Industry Questionnaires, EPA Contract CPA 70-21.
(15 of 30 plants reported relevant data)

2.6 Projection of Industry Demand Growth

Forecasts of future growth in the aluminum industry have been made periodically by informed minerals economists both inside and outside of government. Referenced to projections of compounded annual growth factors of increasing gross national product, expanding markets in end-use consumer markets in virtually all sections of the economy, availability of raw materials, aggressive marketing efforts, and the metal's versatility, these forecasts are consistent and there is every reason to believe that aluminum will continue to be a major growth metal for many years.

It should be noted, however, that the forecasts of economic growth in the primary aluminum industry used in this report, were not obtained from the primary producers or from any other sources within the primary aluminum industry. Consequently, these economic forecasts are not intended to reflect any judgment by the primary producers as to long-term future growth of the primary aluminum industry.

There is a considerable range of optimism among these forecasts - according to the period in which they were made and the interpretations of the growth trends on which they were based. In the light of past experience they are sound, but not precise, and as they are extended beyond a relatively short period (10-15 years) the spread between high and low estimates becomes very wide.

Translation of these forecasts of world consumption into terms of demands for domestically produced primary aluminum requires consideration of the secondary metal contributing to total supply, the proportion of world demand represented by U.S. consumption, and the international trends which may affect the competitive position in the U.S. primary markets.

Five of these forecasts are compared in Tables 2.11 with extrapolation based on their findings. There is a reasonable area of agreement with respect to United States consumption in the median projections of the latest three extended out to the year 2000, and the growth rate assumed by the most recent is accepted as being credible for the analysis.

Table 2.11a COMPARISON OF FORECASTS OF FUTURE ALUMINUM CONSUMPTION

		(a) World Consumption				
		Landberg[1]	Petrick[2]	Brubaker[3]	Metals Week[4]	Stamper[5]
Year Made		1963	1967	1965	1969	1970
World Consumption				(non-communist)		
Base Year		1960	1965	1965	1967	1968
Base Tonnage x 10^6 short tons		-	7.42	5.8	8.65	11.3
Growth Factor Median %		-	9.5	6.8	8.1	6.4
Estimates 10^6 short tons/yr						
1970		-	-	-	-	-
1980	Low	-	-	14	-	-
	Median	-	28.73	19	-	-
	High	-	-	22	-	-
1984	Low	-	-	-	-	-
	Median	-	-	-	32.5	-
	High	-	-	-	-	-
2000	Low	-	-	-	-	53.9
	Median	-	-	-	-	83.2
	High	-	-	-	-	112.4

Table 2.11b COMPARISON OF FORECASTS OF FUTURE ALUMINUM CONSUMPTION

	(b) U. S. Consumption				
	Landberg[1]	Petrick[2]	Brubaker[3]	Metals[4] Week	Stamper[5]
Year Made	1963	1967	1965	1969	1970
			(U.S. plus Can.)		
Base Year	1960	1965	1965	1969	1968
Base Tonnage x 10^6 short tons	2.13	2.75	-	4.15	4.31
Growth Factor Median	5.5	5.8	6.2	7.0	6.45
Estimates 10^6 short tons/yr					
1970	(3.63)	-	-	-	-
1980					
Prim. Ingot	5.66	-	(8.0)	11*	-
Sec. Supply	0.61	-	(1.4)	2*	-
Total - Low	3.82	-	-	-	-
Median	6.27	6.41	9.4	13*	-
High	11.18	-	-	-	-
2000					
Prim. Ingot	13.28	-	(21.1)	(28.1)	(25.8)
Secondary	2.94	-	(3.7)	(5.1)	(5.8)
Total - Low	7.31	-	-	-	21.2
Median	16.22	11.1	(24.8)	(32.2)	31.6
High	34.15	-	-	-	42.0

* For 1984
( ) Extrapolated or ratioed
1/ Landberg, Fischman and Fisher, Resources in America's Future, Johns-Hopkins Press, 1963
2/ A. Petrick, Proc. Council Economics, AIME, 1967
3/ S. Brubaker, Trends in World Aluminum Industry, Resources for the Future, Johns-Hopkins Press, 1967
4/ Farin and Riebsamen, Aluminum, a Profile of an Industry, McGraw Hill, 1969
5/ J. Stamper, Aluminum, Minerals Facts & Problems, U.S. Bureau of Mines, 1970

2.6.1 Review of Forecasts

The industry trade publication, Metals Week, in their study, "Aluminum, A Profile of an Industry", comments on three previously made studies on the future of aluminum as follows:

> "Alfred Petrick, Jr., economist for the Bureau of Mines, estimated in 1967 that world aluminum consumption in 1980 would reach 29-million tons, or about four times the 1965 level of 7.4-million. In a study entitled "World Demand for Mineral Products and the Shifting Supply of Mineral Raw Materials", Petrick emphasized that there is still plenty of room for world expansion despite major inroads into copper's electrical markets. Petrick used a 9.5% growth rate for the 1965-1980 period.
>
> "Resources in America's Future, a 1963 book of unprecedented scope backed by the Ford Foundation, expected US aluminum consumption to be three and one-half times as high in the year 1980 as in 1960, and about two and one-half times as high in the year 2000 as in 1980. Since US consumption in 1960 was about 1.6-million tons, this would place 1980 use at 8.7-million tons, rising to 14.7-million tons by 2000.
>
> "Yet, the book projects three consumption levels. It says that, 'if all factors favor the demand for the metal, consumption by 1980 may rise to six times' what it was in the early 1960's, and by 2000 'to three times that of 1980'. However, it adds that even under the least favorable circumstances, an increase of about 120% by 1980 seems to be in the cards, although the subsequent 20 years might see only a 90% gain. The third projection is a median of the high and low.
>
> "Sterling Brubaker, in his 1967 book, Trends in the World Aluminum Industry, concludes that through 1980 a 5-8% annual growth rate for the Free World is a possibility, with 7% as the most likely figure. He derived these figures from per capita growth rates worked out by the United Nations in 1962.

> "By extrapolating from 1964 information, Brubaker then arrived at a Free World consumption for 1980 of about 19-million tons. Accordingly, he established a range of about 14-million to 22-million tons as being possible for that year.
>
> "Brubaker's analysis is easily the most exhaustive and perceptive of the three largely, presumably, because unlike the others, he deals only with aluminum. Appropriately, he notes that forecasters - including the industry itself - have 'had a very spotty record of success in making estimates of future consumption by a variety of statistical techniques'. He adds, however, that no definitive forecast of future demand is required, since, fortunately, long lead times are not required for supply to react to demand."

Metals Week, in preparing its own forecasts of the future of aluminum, enlisted the cooperation of the managements of seven of the major world aluminum producers in analyzing the factors which would affect demand and supply, during the period from 1969 to 1984. Considered in this study were anticipation of application developments and changes, interrelationships of the industry throughout the world, future of power costs and sources, forward and backward integration, influence of emergent nations, competition with other materials, possible technological changes and analyses of market and utilization changes.

The conclusion of this study is that the past pattern of world aluminum growth trend is not expected to change much in the coming 15 years, and that between now and 1984 total aluminum shipments are expected to triple. That magnitude of increase calls for a continued demand growth of 7-8% reaching perhaps 11-14 million tons in 1984.

In the 1970 volume of the authoritative "Mineral Facts and Problems" published by the U.S. Bureau of Mines, Mr. John Stamper has made an in-depth analysis of future aluminum demand, projecting to the year 2000. His forecast, based on analysis of the probabilities of technological, social and economic changes and their possible effects during the period, places the range of United States demand for aluminum metal in the year 2000 as between 21.2 million and 42 million tons, corresponding to an average annual rate of growth between 5.1% and 7.4%.

To establish a forecast base, domestic aluminum demand in each of 14 end-use categories was projected by Stamper on the basis of a number of considerations which included:

Qualitative and quantitative correlations with projections of growth in gross national product (GNP). Federal Reserve Board index, and other general economic indicators;

Short term (5-10 years) and long term (10-40 years) projections published by Resources for the Future, Inc., and other organizations;

Projections for specific items, such as number and type of motor vehicles and aircraft, growth in expenditures for irrigation, pollution control, and other equipment, and growth in industrial chemicals and steel.

Using econometric techniques and judgment, a forecast base in each of the end-use categories was established.

A number of contingent changes in technology and in the economic mix were then considered that could have a positive or negative influence on the forecast base for each of the end-uses, in order to arrive at a high and low forecast range for each end-use. Interrelations between end-uses were evaluated to determine compensating inverse demand effects and the resulting probability that total aluminum demand would fall within the forecast range.

The results of these forecasts are shown in Table 2.12.

Primary aluminum demand is defined by Mr. Stamper as total demand for aluminum less that quantity recovered from secondary sources, and the forecast for primary demand is based on the assumption that the present proportion of secondary recovery to total demand will not undergo a marked change. Continuation of the current share of

Table 2.12

CONTINGENCY FORECASTS OF DEMAND FOR ALUMINUM

BY END USE, YEAR 2000

(Million Short Tons)

End Use	Demand 1968	U.S. forecast base 2000	Demand in Year 2000			
			United States		Rest of the World	
			Low	High	Low	High
Metal:						
Building and construction	1.00	4.5	4.0	6.0	NA	NA
Motor vehicles	.67	2.7	2.7	6.0	NA	NA
Aircraft and parts	.17	.8	.4	1.0	NA	NA
Shipbuilding and repair	.02	.4	.4	1.0	NA	NA
Railroad	.02				NA	NA
Electrical	.60	4.5	4.0	8.0	NA	NA
Fabricated metal parts (consumer durables)	.47	4.0	3.5	5.0	NA	NA
Machinery and equipment (except electrical)	.31	4.2	2.5	6.0	NA	NA
Metal cans and containers, and packaging	.46	2.3	1.4	5.0	NA	NA
Highway and street construction	.06	.4	.3	1.0	NA	NA
Other manufacturing and fabrication[1]	.53	2.1	2.0	3.0	NA	NA
Total	4.31	-	21.2	42.0	NA	NA
Bauxite and Alumina:[2]						
Abrasives, aluminous	.08	.3	.2	.4	NA	NA
Chemical and allied products	.16	.7	.5	1.0	NA	NA
Nonclay refractories	.16	.6	.5	1.0	NA	NA
Total	.40	-	1.2	2.4	NA	NA
Grand Total	4.71	-	22.4	44.4	31.5	68.0
			(Median 33.4)		(Median 49.8)	

NA—Not available.

[1]—Includes aluminum content of some alumina and bauxite (see fig. 1).

[2]—Aluminum content of bauxite and alumina.

SOURCE: Stamper - Mineral Facts & Problems, U.S. Bureau of Mines, 1970.

the market by the independent secondary aluminum industry and the proportion of aluminum recovered from old aluminum scrap in relation to that recovered from new scrap is also implicit in this assumption. The forecast presents the future breakdown between primary and secondary metal as follows:

United States Aluminum Demand
(Millions of Short Tons)

	1968	2000		
		Low	Median	High
Primary	3.5	17.3	25.8	34.4
Secondary	0.8	3.9	5.8	7.6
Total	4.3	21.2	31.6	42.0

2.7 United States Capacity Growth

If the order of magnitude of future U.S. demands for new primary aluminum metal is accepted as being between 9 and 14 million short tons in 1984, rising to between 17 and 34 million tons in 2000, the problems affecting future domestic capacity growth require analysis. The degree to which domestic capacity will expand is not, as it has generally been in the past, in a simple relationship to demand growth.

Historically, domestic consumption of aluminum has been supplied in the greater part by domestic production from primary and secondary sources; lesser but occasionally important supply has been furnished by withdrawals from accumulated Government stockpile, and by a small net balance of imports over exports.

2.7.1 Secondary Supply

As has been noted before, the bases for forecasts of future new primary metal demand have included the premise that the future contribution to total supply from secondary metal will continue as a constant proportion of that supply.

2.7.2 Stockpile

The U.S. Government aluminum stockpile, after revision in its objectives, has been used in recent years as a mechanism to permit orderly expansions of the industry with private capital by accepting "puts" to the stockpile during periods of slack demand and "takes" by participating companies to ease pressures when demand pushed capacity. Large amounts of aluminum had been added to this stockpile in the mid-1950's, a systematic disposal plan of the surplus was instituted in 1965 which provided for the participating companies to purchase about 1.45 million tons over a period of 16 years.

The relationship of this stockpile movement to domestic primary production is illustrated in Figure 2.4.

The use of Government stockpiles to adjust pressures on primary production has been an influence on the industry growth in the past. It is expected that stockpiling policies with respect to defense goals, acquisitions, and releases will continue to have impact on domestic supply and demand, but to a lesser relative degree than in the past as the production and capacity of the industry increase.

2.7.3 Foreign Trade

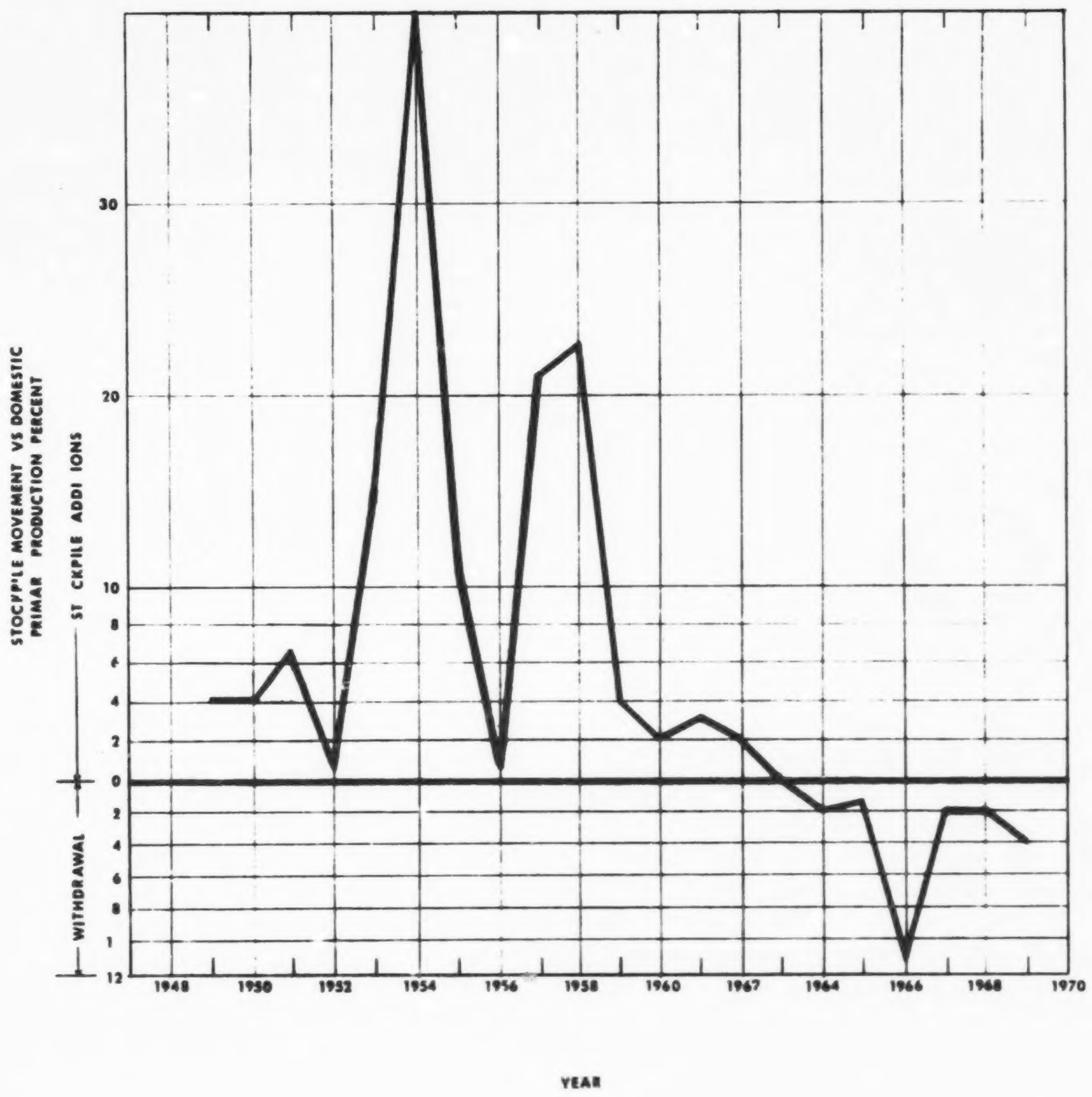
Imports of primary aluminum in the form of ingot and mill products have been a minor, but increasing, factor in the domestic industry supply since the mid-1940's. A major component of this import trade has been the movement of metal from the largest Canadian producer to its U.S. fabricating subsidiaries, representing an intra-company activity. Such shipments have accounted for 70 to 80% of primary aluminum metal imports in recent years (1967-1968).

Exports of primary aluminum ingot have also occurred, growing from a few thousand tons in the early 1950's to several hundred thousands in the 1960's, but a net import balance has existed in every year except 1960. The trend of this net import balance has shown a steadily increasing growth over the past two decades, with cyclic interruptions, as shown in Figure 2.5.

FIGURE 2.4

PROPORTION OF PRIMARY PRODUCTION

REPRESENTED BY STOCKPILE MOVEMENT

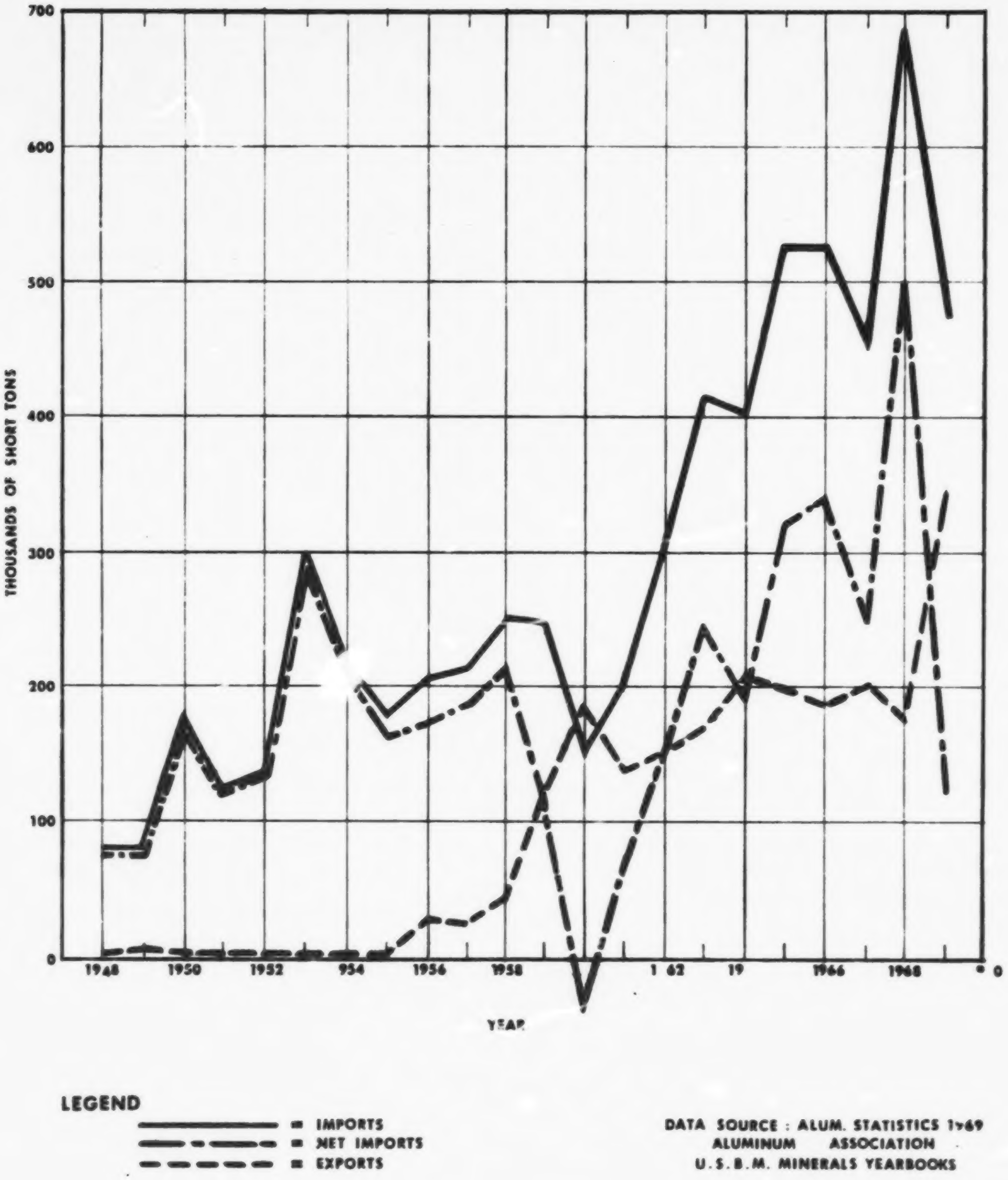


DATA SOURCE US BUREAU OF MINES MINERAL YEARBOOKS

FIGURE 2.5

ALUMINUM INGOT

U.S. IMPORTS & EXPORTS



DATA SOURCE : ALUM. STATISTICS 1969
ALUMINUM ASSOCIATION
U.S.B.M. MINERALS YEARBOOKS

The interrelationship among the interests of the major producers, both foreign and domestic, increasingly facilitates exchange of materials and metal, and tends to result in end-use markets being supplied from the most economical sources. Aluminum price stability has resulted from a high degree of integration of the larger producers, and this integration has extended through participatory interests to all parts of the world.

It seems probable that the importance of imports in contributing to domestic primary aluminum supply will continue to grow and exert considerable influence on the future expansion of domestic capacity. When the net import position is compared to domestic primary aluminum production over the past twenty years it is apparent that foreign primary metal, once a modest part of the supply picture, is finding an important market in the United States.

2.7.4 Duties and Tariffs

U.S. trade policy has steadily reduced tariffs on aluminum products, while eliminating the dutues on bauxite and alumina by renewals of temporary suspensions. Other important aluminum-consuming countries, with few exceptions, have limited reductions of their own duties from high levels to levels still above the U.S. duties. Some countries have imposed special taxes on imported aluminum, either not applicable to domestic aluminum or else higher than similar taxes imposed on domestic metal. Protectionism for domestic aluminum industries has been especially strong in Australia, India, Japan, France, Italy and Brazil.

2.7.5 Internationalization

The international character of the industry in terms of producers' interests extending beyond national boundaries has become increasingly marked during the past decade, with joint ventures participating in new plants and sharing in both material supplies and markets for outputs. As an instance, on the primary production level alone, the three major United States producers collectively have interests in Brazil, India, Mexico, Surinam, Venezuela, the United Kingdom, Norway, Ghana, Australia, and Canada. Conversely, European producers hold interests in several

United States operations. The world-wide character of foreign investment in existing and planned primary plants by some of the world's largest producers is indicated below:

Producer	Foreign Production Investment-Countries
Alcoa	5
Reynolds	6
Kaiser	4
Alcan	8
Pechiney	5
Swiss Aluminum	8

This internationalization has many obvious ramifications affecting aluminum supply, fabrication, marketing, and technical exchange, and influences production patterns, economics, and inter-country movement of primary metal. An instance of this is cited previously where it is noted that the greater portion of U.S. imports of primary metal to-date have represented shipments of Canadian produced ingot to U.S. subsidiaries for fabrication into semi-finished or finished products.

It is noted that the internationalization of the aluminum industry which has gained momentum in the past decade will undoubtedly have an effect on the extrapolation of growth in the domestic primary aluminum production. Requirements for new capacity and expansion in the United States will be affected by moves on the part of major producers to add primary capacity outside of the United States - near bauxite, for instance - in order to reduce costs, and then import the resultant metal. If world tariffs continue to decline, as they are expected to do, this line of action would appear to be more and more attractive.

There is certainly a further factor which may influence the growth of domestic capacity, that of increasing local governmental pressure in areas of bauxite supply to carry the conversion of ore through refined alumina to primary metal within the national boundaries, in order to obtain maximum value utilization of indigenous raw materials resources.

To put this latter problem into perspective, the most recent (1968) figures reported by the U.S. Bureau of Mines indicate that only 6% of the U.S. metal output was derived from domestically mined bauxite. The balance of the primary aluminum production was derived from imports of alumina (17%), or from alumina domestically produced from imported bauxite (65%). It is doubtful that the domestic production of bauxite, 95% of which is mined in Arkansas, could be expected to supply 10% of the future U.S. needs for alumina. Economic utilization of alternate domestic sources of aluminum, such as non-bauxite clays, is still in the future.

The nationalistic pressures noted above are particularly evident in the newly independent and undeveloped countries in which an important portion of the world's bauxite production comes; Jamaica, Guyana, Surinam, and Guinea may be cited. All are forcing conversion of bauxite to alumina before shipment as a matter of government policy, and some are pressing actively for further integration including metal production.

2.7.6 Projection of Growth Possibility

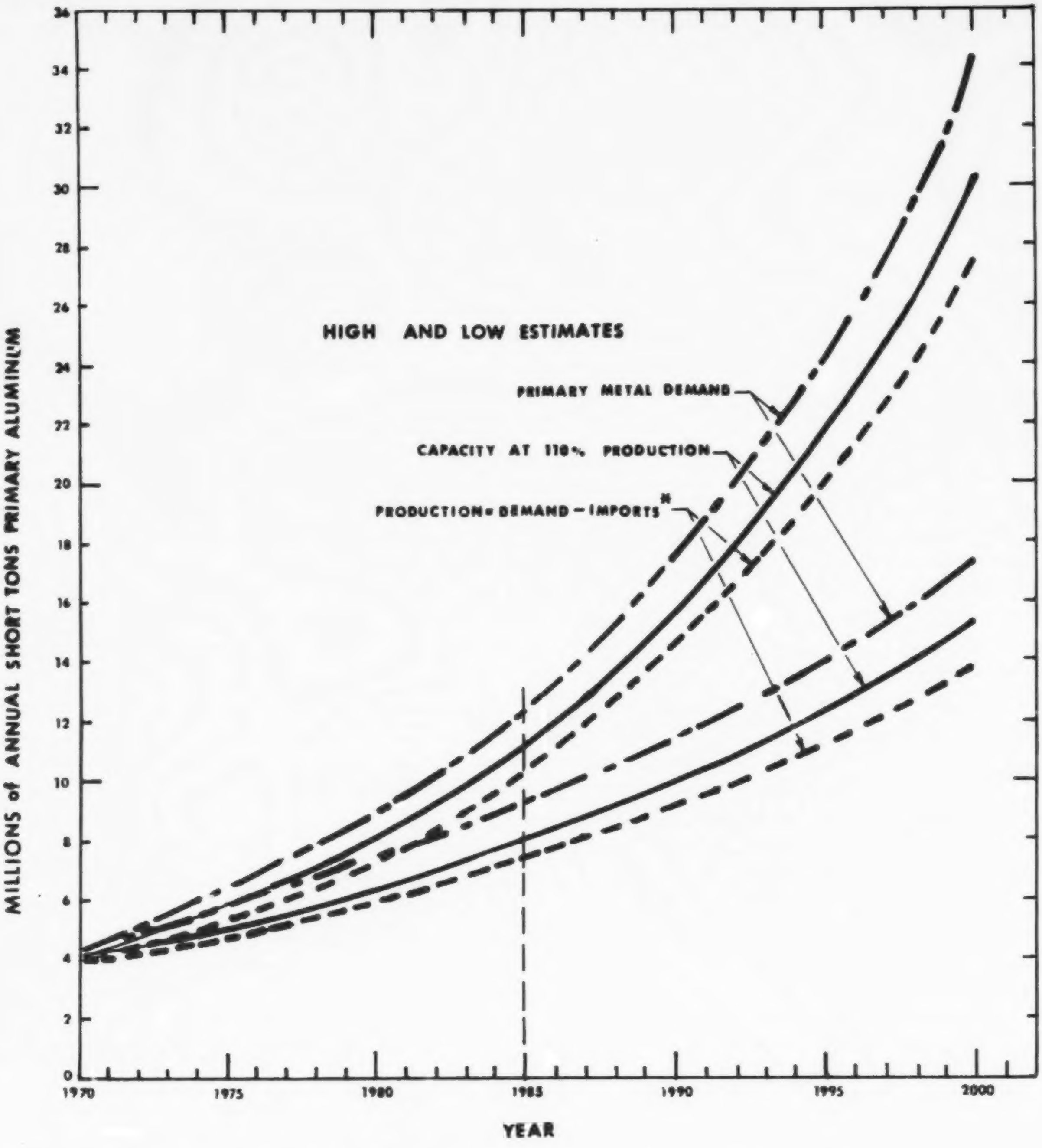
Considering the impact of the factors discussed above on the supply-demand relationship of the domestic industry in the future, it appears possible that the average increase in future domestic production may be within the limits indicated in Figure 2.6, derived from Stamper's projections of demand and an assumption, believed to be conservative, that imports will supply as much as 20% of domestic requirements of new metal by the year 2000.

The gap between 1971 capacity and future production requirements will be closed by capacity expansion on the part of existing producers, as well as by the entry of a certain number of new domestic producers attracted by the expanding domestic market. Whether imports will expand to the degree assumed, both proportionately and in total, seems very possible.

The apparent ranges of increased domestic production are to levels of 8.5-15 million short tons in 1984 and to 14-28 million short tons by the year 2000.

FIGURE 2.6

UNITED STATES PROJECTIONS FOR DEMAND, CAPACITY, AND PRODUCTION OF PRIMARY ALUMINUM



*ASSUMED TO GROW FROM 10% TO 20% OF DEMAND FROM 1970 TO 2000.

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3.0 Technology of Aluminum Production

An understanding of the technology governing the production of aluminum, and of the mechanisms by which pollutants are released from the processes, provides a background for the evaluation of the problems reducing effluents through adjustments of operating techniques and the application of control systems best suited to the various kinds of aluminum smelters.

3.1 Reduction of Alumina by Hall-Heroult Process

All of the production of primary aluminum metal in the United States has been, and is, by the electrolytic dissociation of alumina dissolved in a molten bath of cryolite (Hall-Heroult process), and the following discussion is limited to that technology.

Several theories have been proposed to account for physical changes which occur during the electrolysis of aluminum oxide. However, the high reactivity of the complex electrolyte combined with the high operating temperature make it difficult to determine experimentally which ions are present. Little is known about the exact reaction mechanism beyond that it is complex and is variable with both temperature and with the concentrations of the several bath constituents.

Alumina (Al_2O_3) is dissolved in molten cryolite (Na_3AlF_6) and is reduced to aluminum metal by direct current electrolysis. The released oxygen rises through the electrolyte and reacts with the sacrificial carbon of the anode, while the molten aluminum settles to the bottom of the reduction cell.

Cryolite bath is gradually lost from the reduction cell through absorption in lining materials, electrolysis, and vaporization. Although the quantity varies among aluminum reduction plants, about 20 to 50 pounds of cryolite must be added to the bath per 1000 pounds of aluminum produced in order to make up for these losses.

The stoichiometric weight ratio of sodium fluoride to aluminum fluoride in molten cryolite is 1.50 but experience has shown that maximum current efficiency for the reduction of alumina occurs when this bath ratio is adjusted to fall between 1.30 and 1.45. Sodium impurities carried by the feed alumina accumulate in the cell bath; they react with cryolite to form additional sodium fluoride and thus increase the bath ratio. 3.1/ Two additional factors act to deplete the bath of aluminum fluoride or enrich it in sodium. The vapor pressure of $NaAlF_4$ over molten cryolite is approximately 30 times that of NaF with the result that vaporized bath is depleted in aluminum by vaporization. Also, cryolite, Na_3AlF_6, will react with water to form NaF and Al_2O_3, which tend to remain in the bath, and HF which leaves as a gas. Optimum bath ratio is maintained by the periodic addition of aluminum fluoride to the bath at a rate of approximately 0.2 to 0.7 pound of AlF_3 per pound of cryolite addition, or 10 to 30 pounds of aluminum fluoride per 1000 pounds of aluminum produced.

Table 3.1 presents approximate quantities of feed materials required to produce 1000 pounds of aluminum by the Hall-Heroult process as reported in response to the industry questionnaire. These numbers vary from plant to plant and should not be used in determining process weight at specific plants.

Table 3.1

Feed Materials per 1000 Pounds of Aluminum

Alumina	1950 lb
F (cryolite, aluminum fluoride, fluorspar)	44 lb
Calcined Coke	457 lb
Pitch	138 lb
Electric Power	7-8 MWH

Fluoride Balance

Solids and gaseous fluoride effluents from an aluminum reduction cell constitute the most serious aspects of the air pollution abatement problem. Their rates of release vary over a wide range as a result of changes in operating conditions and, more importantly, due to the occasional "working" of the pot when the crust is broken to admit alumina and cryolite to the molten bath or to tap aluminum metal. Furthermore, over the useful life of a pot lining,perhaps three years, a large fraction of the fluoride bath materials added to the pot is absorbed into the lining. These factors, together with inherent imprecision in measuring effluents, have made it impractical in plant operation to determine accurate fluorine balances around the reduction process.

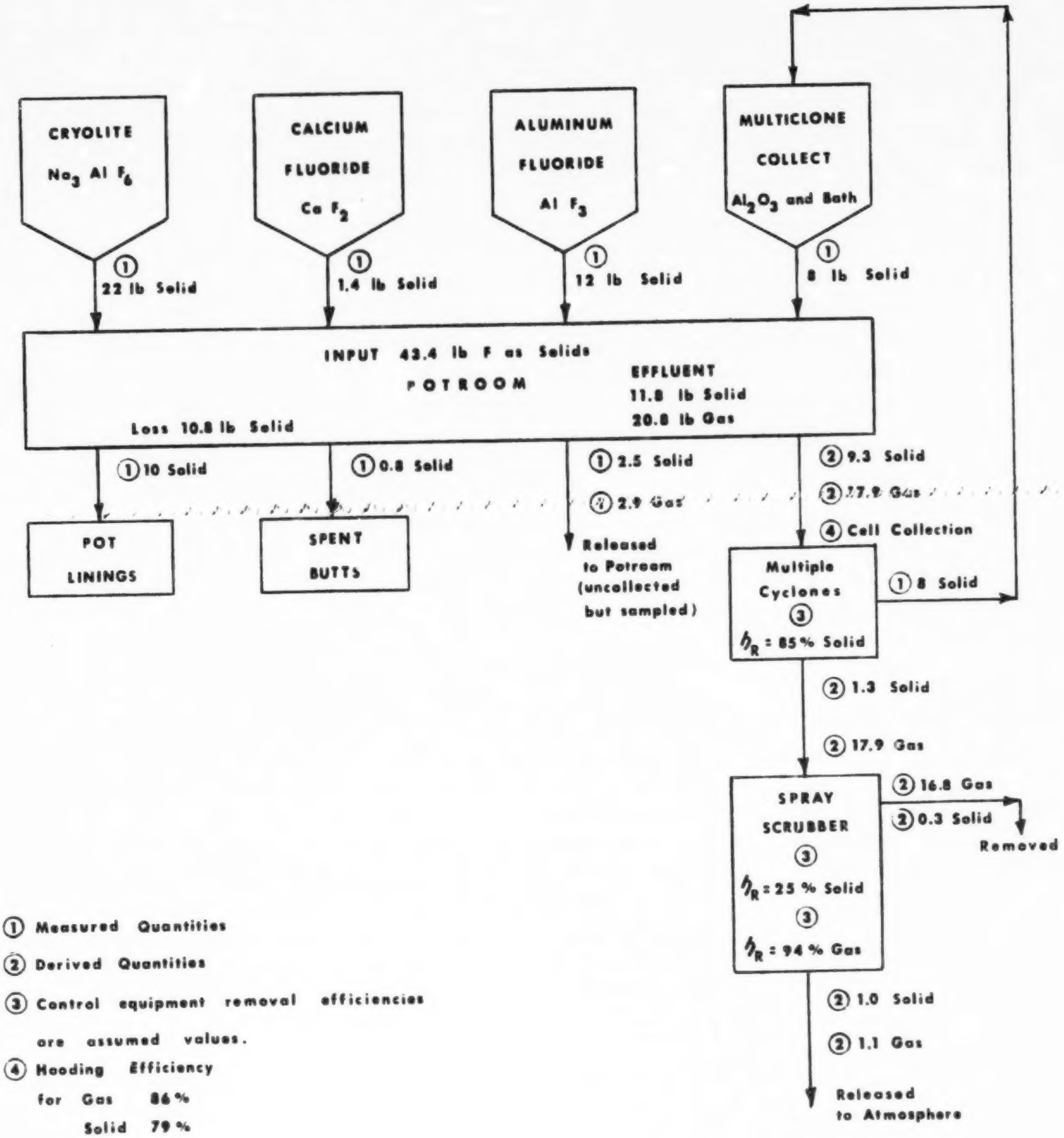
Balances representing the order of magnitude of long term distribution may be obtained by using data on fluoride consumption and recovery, measured over a year or more. One such balance, illustrative of an existing prebake operating potline and its pollution control system, is given in Figure 3.1. This balance indicates a cell effluent of 11.8 pounds of solid "F" and 20.8 pounds of gaseous HF released per 1000 pounds of aluminum produced. These values are higher than those of the industry weighted averages shown in Tables 7.1, particularly with regard to gaseous fluoride, and the differences may illustrate the inherent imprecision in measurements of this sort as well as the variations among operating plants.

Out of the approximately 43.4 pounds of "F" shown as being added to the potline as various solid salts, approximately 32.6 pounds is released from the cell in airborne effluents. Of this, 27.2 pounds is captured by the cell hood collection system for a total "F" effluent collection efficiency of 83.5 percent. The remaining 5.4 pounds, 16.5 percent, escapes to the potroom and leaves by way of roof monitor ventilators. These and other efficiency characteristics of this particular plant air pollution control system example are shown in Table 3.2

In constructing this material balance, the cell input of raw materials and of cyclone collect were determined from annual measured usages. Fluoride in the

FIGURE 3.1

ILLUSTRATIVE
POTROOM FLUORINE BALANCE
PREBAKED ANODE POTLINE
BASIS—POUNDS FLUORINE PER 1000 POUNDS ALUMINUM


CRYOLITE
$Na_3 Al F_6$
① 22 lb Solid
CALCIUM FLUORIDE
$Ca F_2$
① 1.4 lb Solid
ALUMINUM FLUORIDE
$Al F_3$
① 12 lb Solid
MULTICLONE COLLECT
Al_2O_3 and Bath
① 8 lb Solid
INPUT 43.4 lb F as Solids
POTROOM
EFFLUENT
11.8 lb Solid
20.8 lb Gas
Loss 10.8 lb Solid
① 10 Solid
① 0.8 Solid
① 2.5 Solid
② 2.9 Gas
② 9.3 Solid
② 17.9 Gas
④ Cell Collection
POT LININGS
SPENT BUTTS
Released to Potroom (uncollected but sampled)
Multiple Cyclones
③
η_R = 85 % Solid
① 8 Solid
② 1.3 Solid
② 17.9 Gas
SPRAY SCRUBBER
③
η_R = 25 % Solid
③
η_R = 94 % Gas
② 16.8 Gas
② 0.3 Solid
Removed
② 1.0 Solid
② 1.1 Gas
Released to Atmosphere

① Measured Quantities

② Derived Quantities

③ Control equipment removal efficiencies are assumed values.

④ Hooding Efficiency
for Gas 86 %
Solid 79 %

Table 3.2

Potroom Fluorine Balance Control Efficiencies

(Prebaked Anodes with Multiple Cyclones and Scrubbers on a Primary Effluent Collection System - Reference Figure 3.1)

	Indicated Efficiencies, %				
	Primary Collection	Cyclones Removal	Scrubber Removal	Primary Removal	Overall Control
Gaseous HF	86	0	94	94	81
Total Solids	79	85	25	89	70
Total Effluent	84	29	89	92	77

recovered carbon of spent butts and potlinings was determined by averaging chemical analyses of these materials. Quantities of solid and gaseous F escaping the potroom through roof monitors were measured by means of a regular sampling program and other flow rates were derived from assumed removal efficiencies of control equipment and by differences to establish a balance. This illustrative fluoride balance points out the fact that only a part of the consumed fluoride is lost as an effluent; a substantial fraction is absorbed in the cell lining and insulation.

Potline Configuration

The reduction cell, or pot, is a strongly reinforced steel box, lined with heat insulation and with prebaked carbon blocks or a rammed monolithic carbon liner inside the insulation. The carbon liner forms the cathode of the electrolytic cell and provides high electrical conductivity and good corrosion resistance to the highly reactive molten electrolyte. The carbon lining contains steel electric current collector bars that extend through the sides of the steel shell and are connected to a ring collector bus, which is, in turn, connected to the main bus which is usually made of aluminum bars, serving as the electrical connection to a line of cells connected in series.

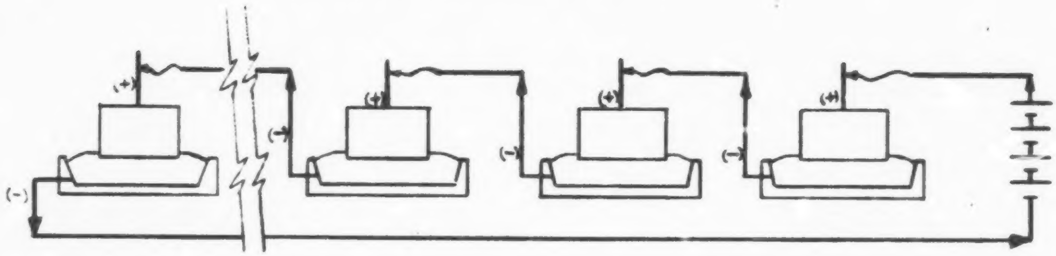
The anode, also made of carbon, is suspended over the steel pot shell and is immersed in the molten electrolyte. It is connected to the main bus system through flexible conductors.

From 90 to 180 reduction cells are linked together electrically in series to form a potline, the basic production unit of the reduction plant. Figure 3.2 shows a schematic electrical diagram. A typical late design potline may consist of 180 cells connected in series and operating at 100,000 amperes and 830 volts, about 4.5 volts drop per cell. Such a potline operating at 83,000 KW would produce approximately 275,000 pounds of aluminum per day with an energy consumption of approximately 7.2 kilowatt hours per pound of aluminum produced.

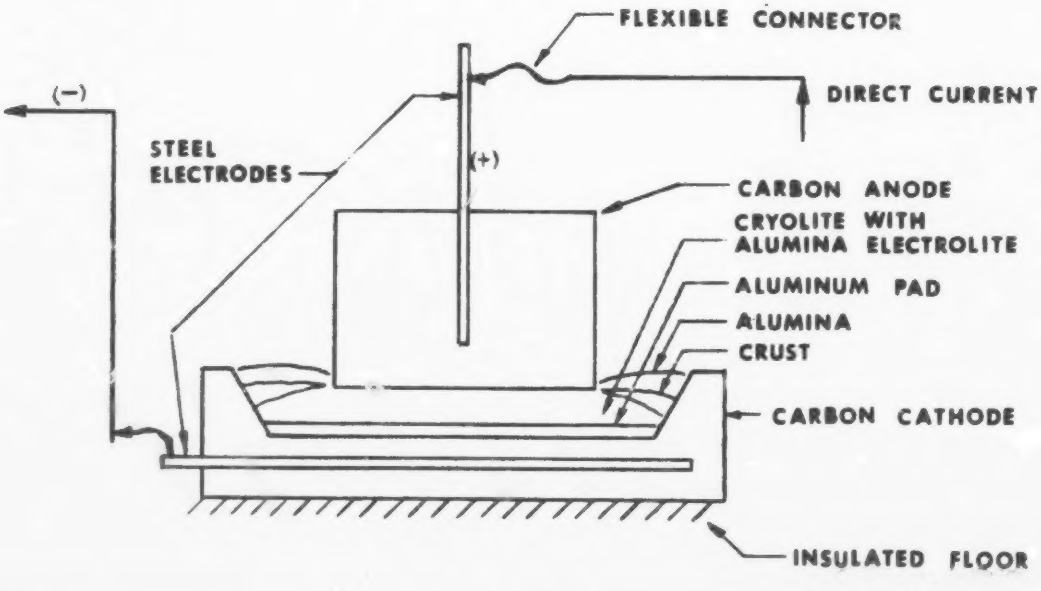
FIGURE 3.2

SCHEMATIC ELECTRICAL DIAGRAM
ALUMINUM REDUCTION CELLS

140 CELLS CONNECTED IN SERIES



SCHEMATIC ELECTRICAL DIAGRAM
ALUMINUM REDUCTION CELL



FLEXIBLE CONNECTOR
(−)
DIRECT CURRENT
STEEL ELECTRODES
(+)
CARBON ANODE
CRYOLITE WITH ALUMINA ELECTROLITE
ALUMINUM PAD
ALUMINA
CRUST
CARBON CATHODE
INSULATED FLOOR

Potline configuration, cell types, and cell dimensions vary according to the design and capacity of the individual aluminum reduction plants, and cell modifications exist within single plants reflecting development of design as capacity expansion has been constructed.

The rectangular bath cavities of modern reduction cells are usually about 10 feet wide and 36 feet long, varying a few feet either way depending on cell type, method of crust breaking and production capacity. Inherent economies associated with the construction of very large cells are offset by structural problems resulting from the swelling of pot linings as they absorb bath material and by operating problems associated with the strong magnetic fields which accompany large electric currents. Recently designed reduction cells range from about 100,000 to about 180,000 ampere capacity, producing 1540 to 2800 pounds of aluminum per day.

Reduction cells are of two basic types, the prebake cell using prebaked carbon multiple anodes, and the Soderberg cell using one large self-baking anode.

3.1.1 Operations

The cell cavity contains molten bath consisting of approximately 85 percent cryolite (Na_3AlF_6), 8 to 10 percent fluorspar (CaF_2) and 2 to 5 percent alumina (Al_2O_3). The molten bath is covered by a crust of frozen electrolyte and alumina. This crust both diminishes heat loss from the top of the cell and protects the anode from oxidation. Periodically part of the crust is broken and stirred into the bath, and fresh alumina is added to cover a newly formed crust.

The electric current decomposes the alumina in solution in the bath. Aluminum is deposited as molten metal on the bottom of the cell and the oxygen is liberated at the surface of the anode where it reacts to form carbon dioxide which is released in the cell gases. The aluminum at the temperature of operation of the cell (about 970°C) is slightly more dense (2.3 gms/cc) than the molten bath (2.1 gms/cc) and thus forms a metal pad on the bottom of the cell. A small portion of the molten aluminum mixes with the bath and is carried to the anode by the circulation of the bath. Here it is oxidized, reducing some of the carbon dioxide to carbon monoxide.

According to Faraday's law, 1000 amperes should produce 17.76 pounds of aluminum per day per cell. In practice, only about 15.4 pounds of metal is produced, so that the current efficiency is about 87 percent and the anode gases contain from 25 to 30 percent carbon monoxide.

The theoretical decomposition voltage of alumina to yield aluminum and carbon dioxide is 1.68 volts. Owing to the resistance of the electrolyte, the carbon lining and the electrical connections, the cell operates at about 4.5 volts resulting in an effective energy efficiency about 35 percent. The remaining 65 percent of the electrical energy input is converted to heat, maintaining the cell at its operating temperature of about 970°C.

Normally the cell operates with about 2 to 5 percent of alumina in solution in the bath, but as the electrolysis proceeds the alumina content is decreased, being intermittently replenished by feed additions. When this content falls to about 1.5 to 2.0 percent the phenomenon of an "anode effect" occurs. It is believed that at this alumina concentration the bath fails to wet the carbon anode and a gas film collects under the anode. This film causes a high electrical resistance and the normal cell voltage increases 10 to 15-fold. To correct the condition the cell crust must be broken and more alumina added to bring the concentration back to its normal content. The gas film under the anode is dispersed and the cell returns to normal voltage.

Whereas the cell bath solidifies at the top and around the sides, forming an insulating crust, the molten aluminum on the bottom of the cell extends under the crust to the cell lining and, therefore, provides a relatively low resistance heat leak through the pot to the surroundings. The depth of molten metal is usually regulated in the range of 4 to 10 inches in order to regulate the operating temperature of the cell by means of this adjustable heat leak. Operating temperature can be held constant in the face of increased cell current by allowing the depth of molten metal to increase and thus increase heat leak to the building.

Metal accumulates in a 100 kiloampere cell at the rate of about 1540 pounds per day. At suitable intervals, usually daily, a large thermally insulated steel crucible is brought to the cells. This crucible has a thermally insulated airtight steel cover with a cast iron siphon attached. The siphon is placed in the cell so that it reaches the bottom of the cell cavity, immersed in the molten metal pad lying on the bottom of the cell. A vacuum is applied to the steel crucible and molten metal is drawn up into the crucible. The amount of metal taken out of a cell is usually about the amount the cell produced in the last twenty-four hour period. The crucible usually taps three or more cells before the steel lid is removed and molten metal in it is "skimmed" to remove lighter bath that might have been tapped with the metal. The crucible is then transported to a cast house where the metal is either poured into a reverberatory holding furnace for casting into various shapes or is poured directly from the crucible into cast iron molds to form "pigs" or "sows". A pig is usually a 50 pound piece of aluminum while a sow varies from 700 to 2000 pounds.

3.1.2 Prebake Cells

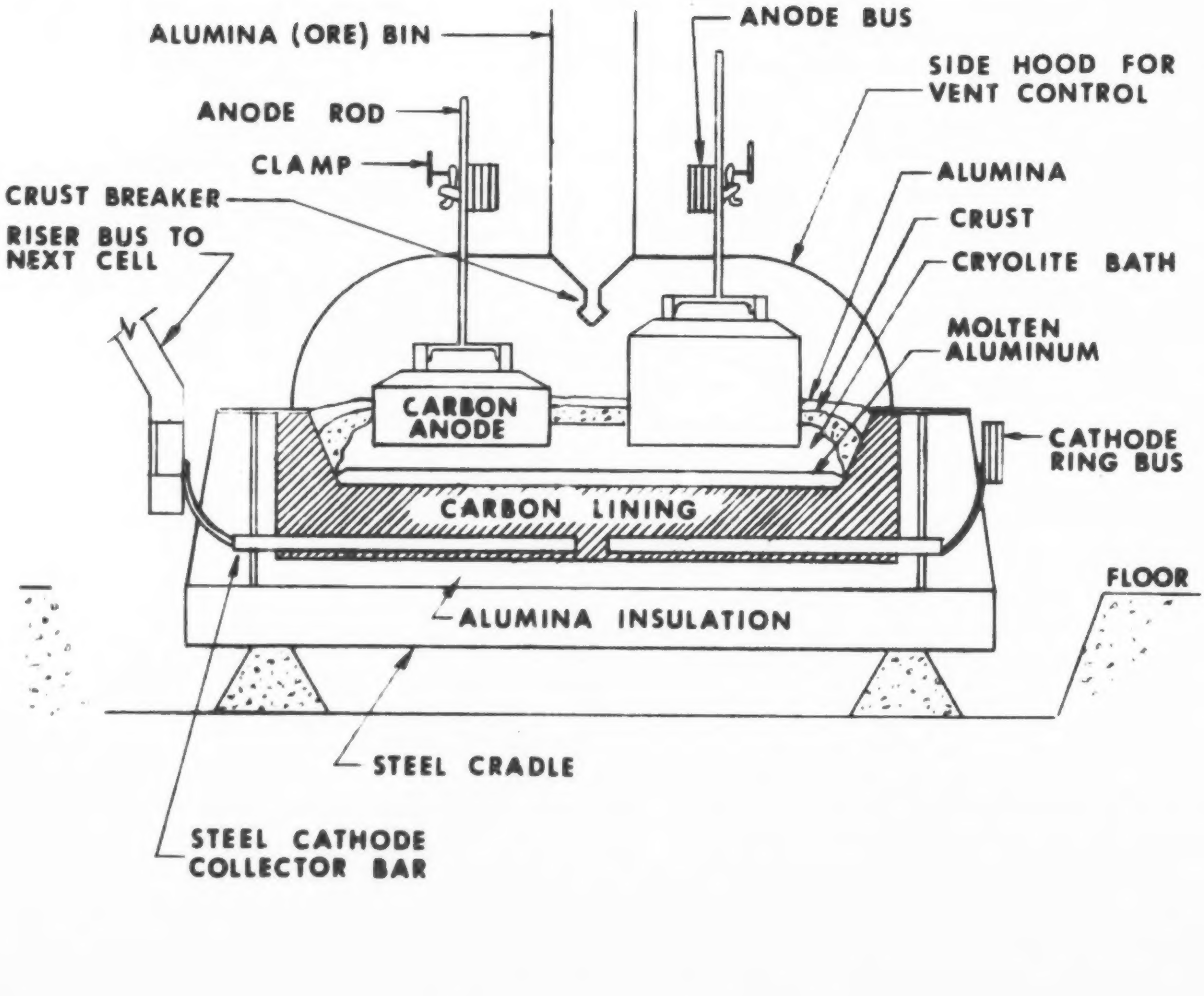
Modern prebake cells use a number of anodes suspended in the electrolyte. The anodes are press-formed from a carbon paste and are baked in a ring furnace or tunnel kiln.

A mixture of coke and pitch is pressed or vibration molded into blocks which are baked at approximately 1200°C to drive off volatiles and to coke the coal tar pitch, cementing the anode into a strong block. The baked anode blocks are moved to a rodding plant where steel stub electrodes are bonded into preformed holes in the blocks. Completed anode assemblies are delivered to the potlines, ready for the replacement of consumed anodes.

Figure 3.3 shows a sectional view of a typical prebake reduction cell with a hood for cell effluent collection.

The newer design prebake cells use up to twenty-six anode assemblies per cell, attached to the anode bus on the cell superstructure by means of clamps. The anode bus is attached to the steel superstructure by anode jacks which may be driven by an air motor or other means,

FIGURE 3.3
PREBAKE REDUCTION CELL
SCHEMATIC ARRANGEMENT


ALUMINA (ORE) BIN
ANODE BUS
SIDE HOOD FOR VENT CONTROL
ANODE ROD
CLAMP
CRUST BREAKER
ALUMINA
RISER BUS TO NEXT CELL
CRUST
CRYOLITE BATH
MOLTEN ALUMINUM
CARBON ANODE
CATHODE RING BUS
CARBON LINING
FLOOR
ALUMINA INSULATION
STEEL CRADLE
STEEL CATHODE COLLECTOR BAR

giving a travel of from 10 to 14 inches and permitting the raising or lowering of all twenty-four assemblies in the cell simultaneously. Each of the twenty-six assemblies may also be raised or lowered individually by means of an overhead crane after the anode clamp is loosened.

The anode assemblies are usually installed in two rows extending the length of the cell. In some arrangements the two rows are closely spaced in the center of the cell, providing a working area on each side of the cell between the cell side lining and the anodes. In other cases the rows are separated and placed closer to the cell side lining, providing the working area in the center of the cell between the rows of anodes.

The sacrificial carbon anodes are replaced periodically by new anode assemblies, the total operating time being dependent on the size of the anode blocks and the amperage of the potline.

The general trend in prebaked anode design has been toward larger anode blocks, obtaining greater effective anode/cathode surface ratios and lower current densities at the anodes for equivalent power inputs.

3.1.3 Soderberg Cells

There are two types of Soderberg cells, each having a single large carbon anode, but differing in the method of anode bus connection to the anode mass. They are termed the horizontal spike suspension (HSS) Soderberg and the vertical spike suspension (VSS) Soderberg. In both, the anode material is a green anode paste which is fed periodically into the open top of a rectangular steel compartment and baked by the heat of the cell to a solid coherent mass as it moves down the casing. This casing is mounted on the steel superstructure of the cell and is raised or lowered by means of powered jacks. Green paste is added to the upper section to replenish the anode as it is consumed.

In the HSS pot, rows of steel studs in channel assemblies project laterally into the paste and move with the anode. They transmit current into the baked anode, and are extracted when, as a result of the progressive consumption of the anode, they have been moved down to a point where they are close to contacting the molten bath.

In the VSS Soderberg, steel current-carrying studs project vertically into the anode through the unbaked paste portion and into the baked portion of the anode. These steel studs are also extracted before they are exposed at the bottom of the anode.

In both cases the steel studs are connected to an anode bus that transmits electric current from the main bus.

Figures 3.4 and 3.5 show schematic diagrams of the two Soderberg cell designs.

In both types of Soderberg cells the in-place baking of the anode paste results in the release of hydrocarbon fumes and volatiles derived from the pitch binder of the paste mixture. These products are a component of the Soderberg cell effluents and are essentially absent from those of the prebaked cells. Their tarry nature requires modification of the control treatment techniques applied to the effluents, as it interferes with pollutant removal devices. With VSS Soderberg cells this modification involves the combustion of the collected hydrocarbon fumes at the cell by means of a burner, converting the tars to gaseous fractions which do not interfere with the operation of subsequent control devices.

The construction of the VSS Soderberg cell with respect to electrode positioning is such that gas collection skirts may be installed between the anode casing and the bath surface, and effluents may be ducted to a burner and the following control devices without interference with cell operations. However, the requirement for side-working the cell results in surface areas with uncontrolled exposure during the crust breaking and charging operations, with accompanying losses of cell effluents from the unhooded surfaces during these operations.

The construction of the HSS Soderberg cell prevents the installation of an integral effluent collection device such as a gas skirt, since the anode casing is formed by removable sections supporting the horizontal spike electrodes, and these sections are periodically changed as the anode moves downward and is consumed. Hooding is restricted to canopy suspension with removable side panel closures, resulting in so much air dilution

FIGURE 3.4

HSS SODERBERG CELL
SCHEMATIC ARRANGEMENT

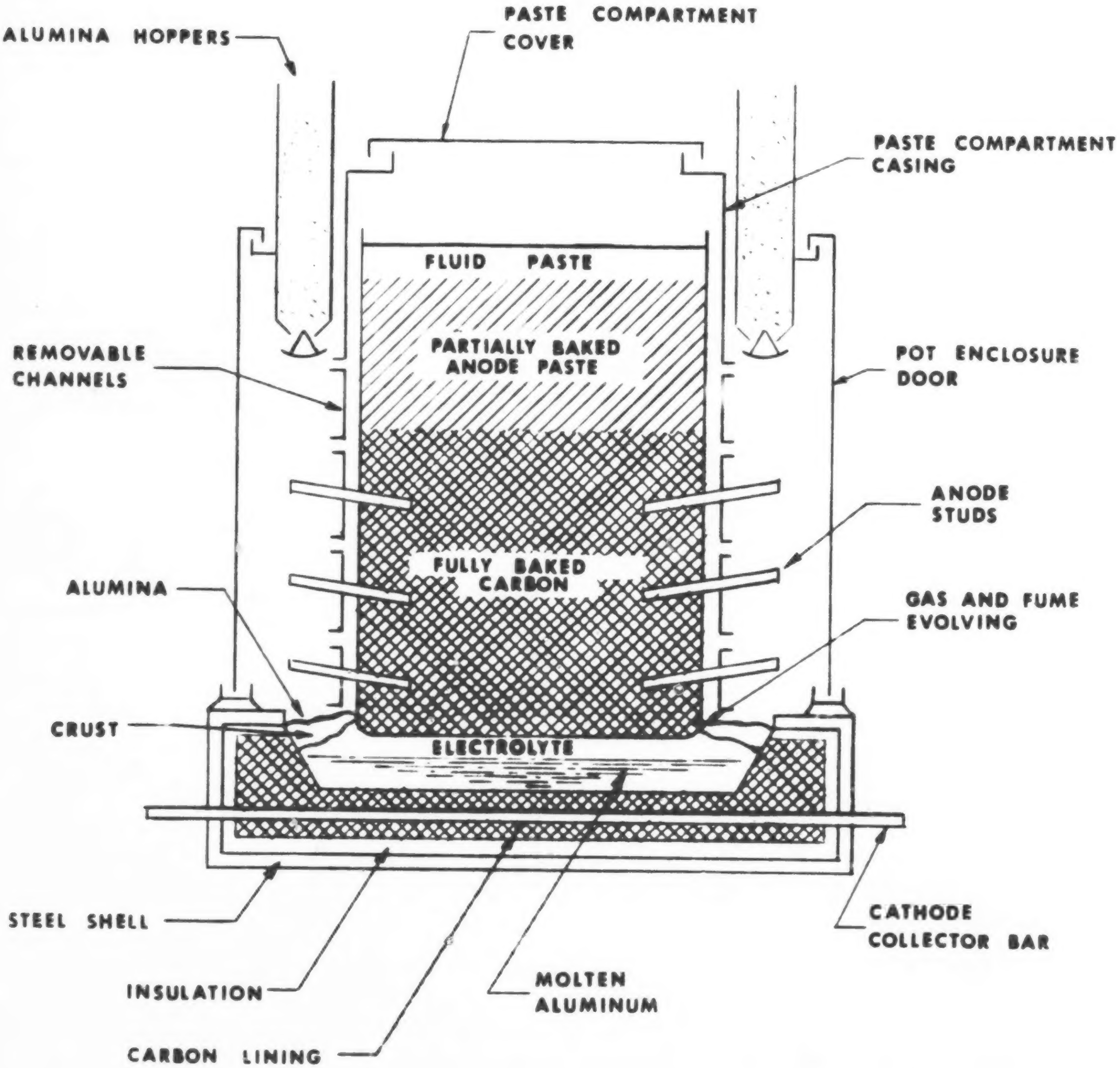
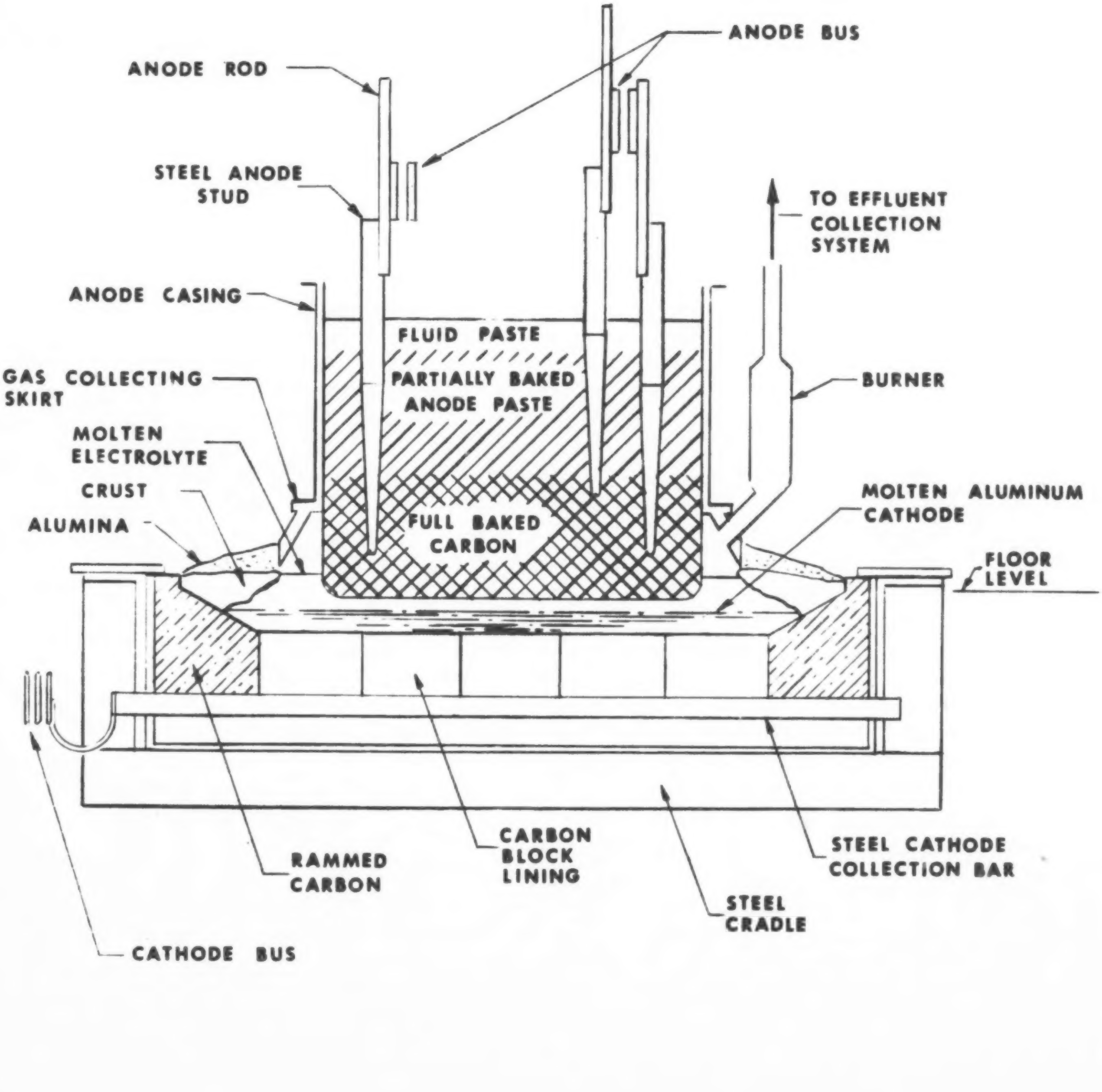

ALUMINA HOPPERS
PASTE COMPARTMENT COVER
PASTE COMPARTMENT CASING
FLUID PASTE
PARTIALLY BAKED ANODE PASTE
REMOVABLE CHANNELS
POT ENCLOSURE DOOR
ANODE STUDS
FULLY BAKED CARBON
ALUMINA
GAS AND FUME EVOLVING
CRUST
ELECTROLYTE
STEEL SHELL
CATHODE COLLECTOR BAR
INSULATION
MOLTEN ALUMINUM
CARBON LINING

FIGURE 3.5
VSS SODERBERG CELL
SCHEMATIC ARRANGEMENT


ANODE ROD
ANODE BUS
STEEL ANODE STUD
TO EFFLUENT COLLECTION SYSTEM
ANODE CASING
FLUID PASTE
GAS COLLECTING SKIRT
PARTIALLY BAKED ANODE PASTE
BURNER
MOLTEN ELECTROLYTE
CRUST
ALUMINA
FULL BAKED CARBON
MOLTEN ALUMINUM CATHODE
FLOOR LEVEL
RAMMED CARBON
CARBON BLOCK LINING
STEEL CATHODE COLLECTION BAR
STEEL CRADLE
CATHODE BUS

of collected effluent that self-supporting combustion in burners is not possible.

As in the VSS Soderberg the side-working area inherent in the cell design complicates the problem of efficient effluent collection.

The relative advantages and disadvantages of the different types of cells are not universally agreed upon within the primary aluminum industry. In the United States, the larger number of installations employ prebaked anode cells. No new VSS Soderberg plants and only one new HSS Soderberg plant was built between 1959-1970, although expansions were carried out in existing Soderberg plants using the existing types of cells. One VSS Soderberg plant was under construction in 1970.

Table 3.3 following summarizes this trend in the United States.

3.2 Carbon Plants

Reduction plant anodes and cathodes are made from anthracite and/or calcined petroleum coke, bonded by pitch and baked to form solid carbon masses.

The preparation of this electrode material in one form or another is usually carried out as an ancillary operation at the reduction plant site. In the United States there is only one reduction plant in which, because it is supplied with fabricated prebaked anodes made at another company-owned facility, the carbon plant is not a part of the on-site operation to supply anode material. Cathode material in the form of prebaked block may be supplied from off-site sources, but usually is prepared on-site in the form of paste used for monolithic rammed lining.

3.2.1 Paste Production Operations

Carbon paste preparation consists of crushing, grinding, screening and classifying, combining of carefully sized fractions with a pitch binder, and mixing. The preparation plant is termed the "green mill" by the industry and may produce anode paste for Soderberg cells, cathode paste, or green pressed anodes for prebake treatment.

Table 3.3 U. S. TRENDS IN ADOPTION OF CELL TYPES

	Prebake Plants			Soderberg Plants					
				HSS			VSS		
	Installations		Expansion	Installations		Expansion	Installations		Expansion
	New	Cumulative		New	Cumulative		New	Cumulative	
Pre 1946	-	10	-	-	2	-	-	-	-
1946	(-3)1/	7	-	-	2	-	-	-	-
1947-1950	12/	8	-	-	2	-	-	-	-
1951-1958	4	12	2	3	5	2	3	3	-
1959-1965	1	13	-	1	6	-	-	3	-
1966-1969	1	14	1	-	6	2	-	3	2
1970	3	17	-	-	6	-	-	3	-
19713/	2	19	-	-	6	-	-	3	-
19723/	1	20	-	-	6	-	1	4	-

1/ - 3 Government-owned (DPC) plants deactivated.

2/ - 1 DPC plant reactivated under private ownership.

3/ - Under construction.

Figure 3.6 shows a typical flowsheet for a Soderberg paste plant.

Figure 3.7 shows a typical flowsheet for the paste preparation and green anode pressing of prebake anodes. Forming of the green anodes is accomplished either by hydraulic molding or vibratory jolting of the stiff anode paste into dimensionally stable blocks ready for baking and rodding.

Solid raw materials (calcined petroleum coke, anthracite coal, solid pitch, and green petroleum coke, as required for various kinds of paste mixes) are received in bulk and conveyed to carbon plant storage. Wetting agent sprays are used in some green mills to reduce dusting conditions inherent in materials handling.

Material is reclaimed from storage, usually by front-end loaders with enclosed cabs, and fed to combinations of crushing equipment in closed circuit with vibrating screens followed by grinding units. Sized fractions of crushed and ground material are separated and stored in mix bins for make-up of paste composition.

Cleaned reclaimed spent anodes and anode scrap from prebake plant operations are similarly crushed and sized for recycle to prebake anode preparation.

Dry solids are drawn from the mix bins in weighed proportions to provide batches of carefully controlled size distribution and composition, which are then transferred to steam jacketed hot mixers. For baked anode pastes the mixer feed contains either solid crushed coal tar pitch which is softened and blended in the mixers or hot liquid pitch to provide the paste binder. For Soderberg paste, a liquid pitch is used, metered to the mixers.

The hot Soderberg paste is discharged directly from the batch mixers to transfer cars which convey it to the cell rooms for anode replenishment, or may be cooled and briquetted.

The prebake paste, less fluid than the Soderberg material, is transferred from the mixers to anode molds, in which the self-supporting green anode is formed by compaction.

FIGURE 3.6
SODERBERG ANODE PASTE PLANT FLOWSHEET

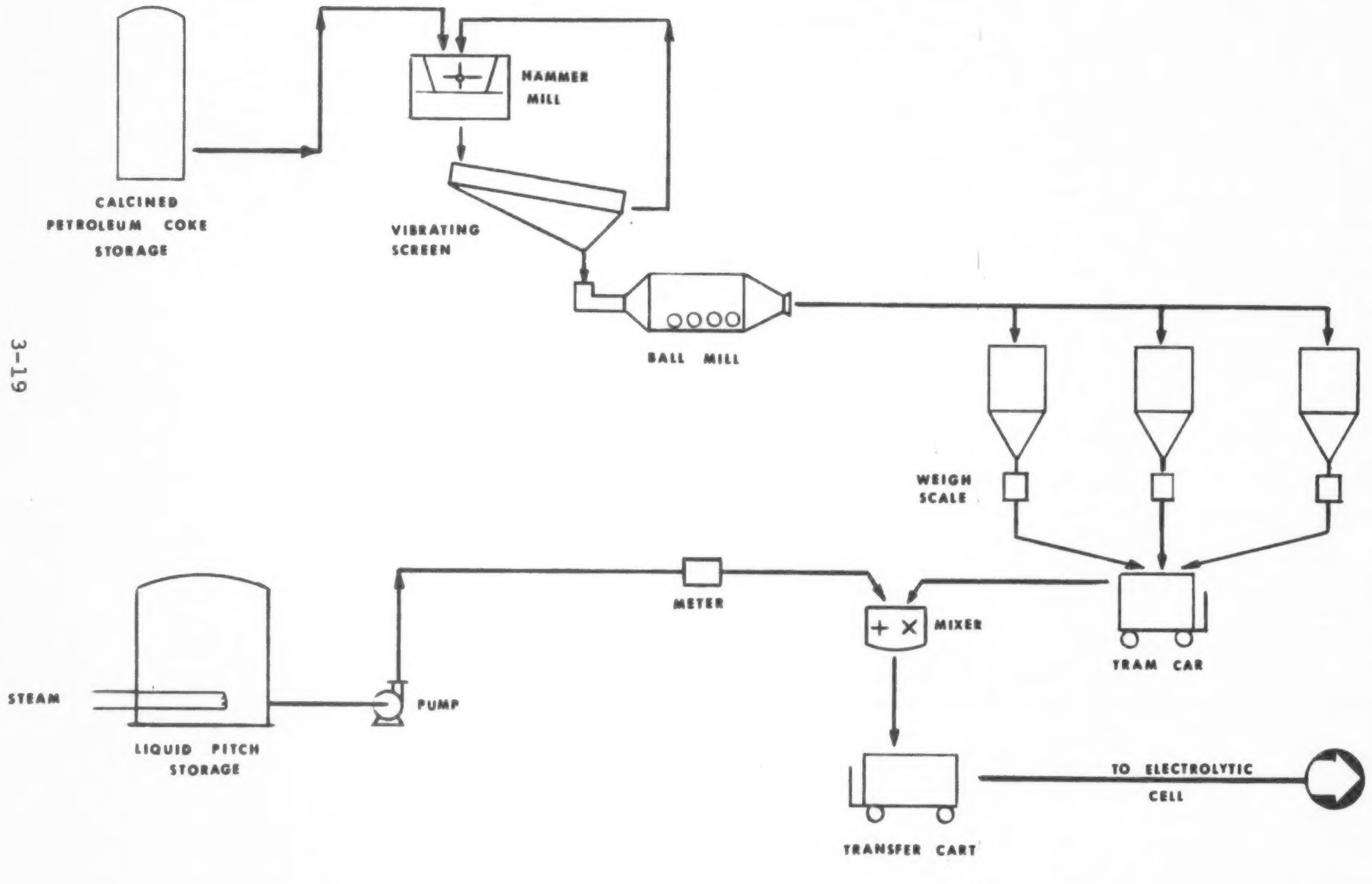
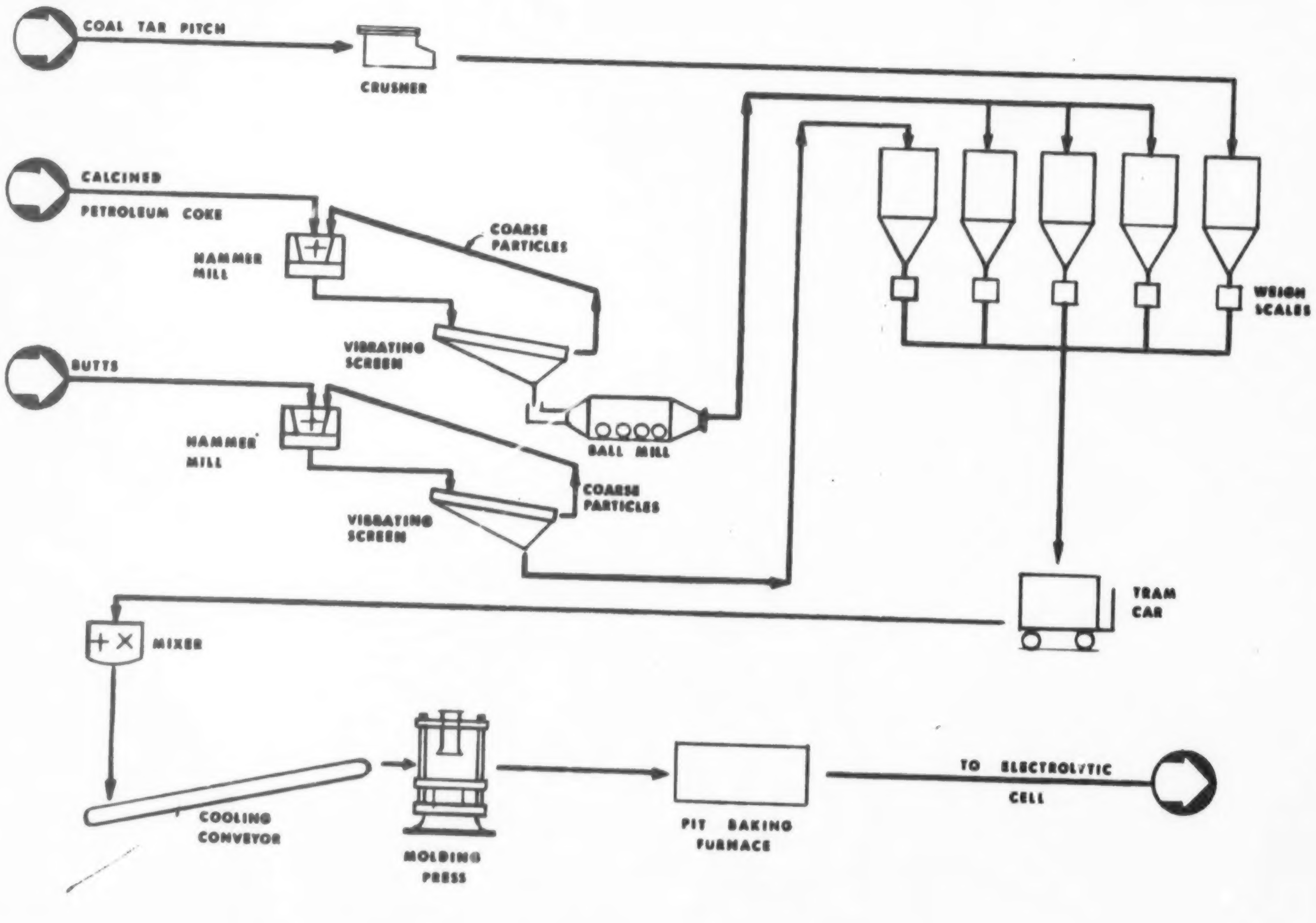

CALCINED PETROLEUM COKE STORAGE
HAMMER MILL
VIBRATING SCREEN
BALL MILL
WEIGH SCALE
TRAM CAR
METER
MIXER
STEAM
LIQUID PITCH STORAGE
PUMP
TRANSFER CART
TO ELECTROLYTIC CELL

FIGURE 3.7
PREBAKE ANODE PREPARATION FLOWSHEET


COAL TAR PITCH
CRUSHER
CALCINED
PETROLEUM COKE
HAMMER MILL
COARSE PARTICLES
VIBRATING SCREEN
BUTTS
HAMMER MILL
BALL MILL
COARSE PARTICLES
VIBRATING SCREEN
WEIGH SCALES
TRAM CAR
MIXER
COOLING CONVEYOR
MOLDING PRESS
PIT BAKING FURNACE
TO ELECTROLYTIC CELL

3.2.2 Baking Operations - Ring Furnaces

Green anodes are delivered to the baking plant, in most of which the furnaces are ring type, sunken, baking pits with surrounding interconnecting flues.

Anodes are packed into the pits, with a blanket of coke or anthracite filling the space between the anode blocks and the walls of the pits. A 10 to 12 inch blanket of calcined petroleum coke fills the top of each pit above the top layer of anodes.

The pits are heated with natural gas or oil fired manifolded burners for a period of about 40 hours. The flue system of the furnace is arranged so that hot gas from the pits being fired is drawn through the next section of pits to gradually preheat the next batch of anodes before they are fired, in turn, when the manifold is progressively moved. The anodes are fired to approximately 1200°C, and the cycle of placing green anodes, preheating, firing, cooling, and removal is approximately 28 days.

The ring type furnaces use outside flues under draft, and since the flue walls are of dry type construction, most volatile materials released from the anodes during the baking cycle are drawn, with the combustion products of the firing, into the flue gases.

Flue gases may be passed through scrubbers and perhaps electrostatic precipitators to reduce temperature and scrub or precipitate out a portion of the hydrocarbons before exhausting to a stack.

The furnace buildings spanning the lines of baking pits are usually open at the side and ventilated through gravity roof monitors without emission controls.

The baked anodes are stripped from the furnace pits by means of an overhead crane on which may also be mounted pneumatic systems for loading and removing the coke pit packing.

Baking Operations - Tunnel Kilns

A second type of furnace, the tunnel kiln, has been developed for application in the baking of anodes. The kiln is an indirect fired chamber in which a controlled atmosphere is maintained to prevent oxidation of the carbon anodes. Green anode blocks are loaded on transporter units which enter the kiln through an air lock, pass successively through a preheating zone, a firing zone, and a cooling zone, and leave the kiln through a second air lock. The refractory beds of the cars are sealed mechanically to the kiln walls to form the muffle chamber, and yet permit movement of the units through the kiln.

The muffle chamber is externally heated by combustion gases, and the products of combustion are discharged through an independent stack system.

Effluent gases from the baking anodes may be introduced into the fire box so as to recover the fuel value of hydrocarbons and reduce the quantity of unburned hydrocarbon to approximately one percent of that coming from a ring furnace. Further reduction of solid and gaseous effluent may be achieved by the use of heat exchangers, scrubbers and electrostatic precipitators.

While the tunnel kiln presents mechanical problems in design and operation, it is reported to have several appreciable advantages over the ring type of furnace. Baking cycle from green to finished anode is much shorter. Anode baking is more uniform. Space requirements for equal capacity furnaces is less. Smaller gas volumes are handled through the furnace emission control system.

The successful development of the tunnel kiln in this application is recent, and to date only one installation is in normal operation.

Baked anodes are delivered to air blast cleaning machines utilizing fine coke as blasting grit. Fins, scarfs, and adherent packing is removed by this treatment, and the baked anodes are then transferred to the rodding room.

3.3 Prebaked Anode Rodding

Anode assemblies returned from the cell room, after initial separation of the spent butts, are delivered to the rodding room where the thimbles forming the connection between the anode blocks and the current carrying rod supports are cracked off and the rod stubs cleaned by grit blasting.

In the green anode forming operation depressions had been molded into the top surfaces of the blocks to receive the rod stubs.

Cleaned baked anode blocks are transferred from the bake plant storage area on roller conveyors to the rodding area for make up into rodded anode assemblies.

Rod yoke assemblies, supported by overhead conveying mechanisms, are indexed in position over anode blocks and connected to the blocks by pouring a cementing material, usually cast iron as a thimble in the holes around the rod stubs. After rodding, the anodes may, in some plants, be sprayed with a metallic aluminum coating.

The completed rodded anode assemblies are then stored for later transfer to the potrooms.

3.4 Cast House Operations

Molten aluminum metal is syphoned from the reduction cells into transfer crucibles, sampled, and conveyed to the cast house, where it may be placed directly in gas-fired holding furnaces, or may be cast into pigs or large sows for later remelt.

Primary metal, after fluxing for removal of minor impurities such as oxides, bath electrolyte, and gas inclusions, may be cast into a variety of ingot forms, including 50 pound unalloyed or alloy ingot, 30 pound casting alloy ingot, or cast extrusion billet, sheet ingot or forging alloy ingot. Cast ingot may be produced continuously from horizontal direct chilled casting machines or intermittently from vertical direct chilled casting machines; other forms are produced on casting wheels or in-line casting machines.

Metal may also be shipped in the molten state directly from the reduction plant to a customer's plant in insulated ladles.

3.5 Fluoride Recovery from Cell Effluents

Every thousand pounds of aluminum produced from alumina requires the replacement to the cell bath of approximately 44 pounds of fluoride, primarily as cryolite (Na_3AlF_6) and aluminum fluoride (AlF_3). These salts serve only as the bath in which alumina is dissolved, and this 44 pounds is lost from the reduction cell mainly through evaporation and dusting from the cell surface. Cryolite and aluminum fluoride presently cost approximately \$260 and \$360 a ton respectively, approximately \$0.25 per pound of F, and their consumption or loss contribute significantly to the cost of producing aluminum. Several methods are used to recover fluoride values which escape from the cell bath as effluents.

3.5.1 Dry Collection of Solids

Some smelters employ multiple cyclone dust collectors on the effluent streams from prebake or VSS Soderberg reduction cells to capture a major portion of the solids which are carried away from the cells in primary effluent collection systems. These particulates consist mainly of alumina but they may contain about nine pounds of F per thousand pounds of aluminum produced, in the form of cryolite, aluminum fluoride and calcium fluoride. Collected in a multiple cyclone separator, these solids may be returned directly to the reduction cells to make up a substantial fraction of the 44 pounds of F required. Figure 3.1 of this section shows an F material balance around a reduction cell in which eight pounds of F is returned to the cell as a multiple cyclone collect.

3.5.2 Adsorption and Dry Collection

Normally, a reduction cell releases nearly twice as much gaseous F as solid F, in the order of 11 to 18 pounds per thousand pounds of aluminum produced, so that its recovery can be even more economically beneficial than the recovery of solid F. Several process systems are in use in which particulate fluorides are captured dry and gaseous fluoride, HF, is adsorbed on alumina and returned to the cell in this form.

3.5.3 Wet Collection

Wet scrubbers in various forms are used to remove gaseous and particulate fluorine from potline effluents. Liquors from these scrubbers, when used with fluoride-bearing spent pot linings or insulation materials, can serve as raw material to plants which produce synthetic cryolite or aluminum fluoride.

3.6 Cryolite Production

As discussed in the preceding section, one route for the recovery of fluorides lost from the reduction cell bath is to capture them in scrubber liquor, combine this with spent pot lining and insulation materials and make synthetic cryolite from these raw materials. Any discussion of fluoride recovery through this route must of necessity include consideration of the various types of cryolite that may be produced and the effects of their uses in aluminum smelting.

There are basically three types of synthetic cryolite; a high purity type containing approximately 95 percent cryolite, a standard type, approximately 90 percent cryolite, and a low grade type containing approximately 50 percent cryolite. Most of the balance is alumina.

High Purity Cryolite

This cryolite contains only a few percent free alumina and very low iron and silica impurities (less than 0.20 percent each).

High purity cryolite may be used on any reduction cell, even those producing 99.90 percent purity aluminum, and it will have little if any degrading effect on the metal purity. This grade of cryolite is the most expensive and its production from cell effluents is not possible without the use of purchased hydrofluoric acid because of the impurities contained in the effluents.

Standard Grade Cryolite

This cryolite contains approximately six percent free alumina and total iron and silicon impurities in the range of 0.70 percent maximum.

Standard grade cryolite may be used throughout most reduction plants with little if any adverse effects on metal grade or cell operation. Only requirements for highest purity aluminum would limit the use of standard grade cryolite. This grade may be produced from cell effluents using equipment which is more expensive and more complicated than that necessary to produce low grade cryolite.

Low Grade Cryolite

This cryolite contains approximately 50 percent free alumina and significant amounts of iron and silica impurities. For this reason, low grade cryolite has limited utility in a reduction plant. Upon addition to a reduction cell, the cryolite is purified. That is, the metallic impurities pass into the molten aluminum in the bottom of the cell leaving the molten electrolyte low in metallic impurities. This phenomenon makes practical the use of the reduction cell primarily for the purpose of purifying low grade cryolite.

Several cells in each cell room may be selected as bath cells. They will be fed the low grade cryolite on a routine basis, and they will be "bath tapped". Bath tapping is done in a method similar to tapping molten aluminum from the reduction cell with the exception that the cast iron siphon is held above the molten aluminum pad. The bath is tapped and is transferred to cast iron tubs where it is allowed to solidify and cool. It is then dumped from the tubs and broken into pieces. It is termed "purified" bath and may be used on any reduction cell in the plant.

The rate at which low grade cryolite may be purified depends upon the number of bath cells that are used and upon the free alumina content of the cryolite being used.

The number of bath cells is usually limited by the amount of high grade metal the plant is trying to produce and by the poorer operating efficiency of bath cells. Of necessity bath cells must be operated at higher voltages than normal cells and they produce a much lower grade aluminum. They have a tendency to run at higher cell temperatures and because of the high free alumina content of the low grade cryolite, they have a tendency to collect muck on the bottom of the cells. When this happens, they must be removed as bath pots until the cell is cleared of the muck. The muck consists of undissolved alumina and causes a higher electrical resistance in the cell than that found in normal cells. Mucky, or "sick" cells as they are sometimes called, operate at much lower ampere efficiency than normal cells and are therefore uneconomical aluminum producers.

It is usually not economical to operate a reduction plant solely on low grade cryolite. Depending upon the grade of aluminum that the plant is required to produce, some combination of low grade and standard or high grade cryolite will be used.

An evaluation of the economics involved in recovering the fluorine value in the cell effluents as either standard or low grade cryolite requires a careful study of their costs relative to their utilities in the reduction process.

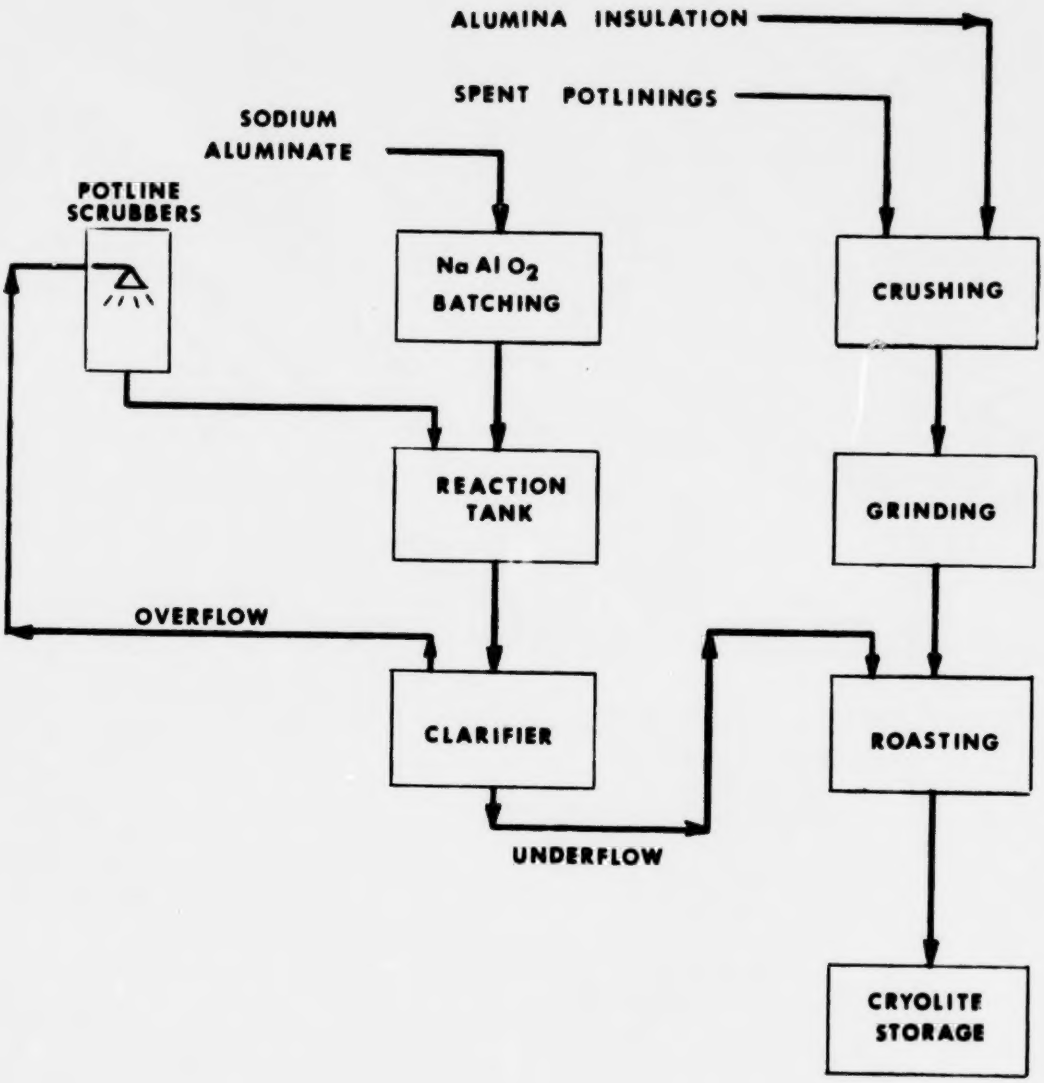
Another factor to be considered is whether the cell effluents contain hydrocarbons or if they do, whether or not they can be easily removed. The following paragraphs describe processes to recover fluorine from scrubber effluents in the absence of hydrocarbons. If the scrubber liquor contains hydrocarbons, a different process flow design must be used to produce standard grade cryolite.

3.6.1 Low Grade Cryolite Recovery

Figure 3.8 shows a block flow diagram of a low grade cryolite recovery system. Potline effluent scrubber liquor containing dissolved fluorides is fed to a reaction tank where sodium aluminate is added. This precipitates cryolite from the liquor and the slurry is fed to a clarifier. The overflow from the clarifier is returned to the potroom scrubbers and the underflow, containing the cryolite, is fed to a classifier, a filter, and a roaster for drying.

Spent pot lining and spent alumina insulation also may be crushed, ground fine and fed to the roaster.

FIGURE 3.8
LOW GRADE CRYOLITE PROCESS BLOCK FLOW DIAGRAM


ALUMINA INSULATION
SPENT POTLININGS
SODIUM ALUMINATE
POTLINE SCRUBBERS
Na Al O$_2$ BATCHING
CRUSHING
REACTION TANK
GRINDING
OVERFLOW
CLARIFIER
ROASTING
UNDERFLOW
CRYOLITE STORAGE

The product of the roaster is a low grade cryolite containing approximately 50 percent cryolite and 50 percent alumina. No information is available on pollution controls associated with the roaster operations.

3.6.2 Standard Grade Cryolite Recovery

Figure 3.9 shows a block flow diagram for one process producing standard grade cryolite from scrubber liquor and spent pot linings.

Spent pot lining material containing cryolite is crushed and ground to about minus 1/2 inch mesh and is reacted in the digester with caustic to produce soluble sodium aluminate ($Na_2Al_2O_4$) with sodium fluoride (NaF).

Slurry from this digestion process is washed in a mud wash thickener to recover entrained fluoride.

Liquor from the thickener containing dissolved aluminum, sodium, and fluoride values, is adjusted to the stoichiometric ratio of cryolite by the addition of sodium fluoride from scrubber water treatment and is acidified by reacting with carbon dioxide, precipitating cryolite from a sodium carbonate solution.

A filter separates cryolite product from sodium carbonate spent liquor and the cryolite, now about 90 percent pure, is dried for storage.

Part of the spent liquor is used to dissolve fluorides in the scrubber water and the remainder is reacted with lime to produce caustic for recycle to digestion.

3.6.3 Cryolite Recovery Costs

Figure 3.10 shows the relationship between estimated capital cost to erect a standard grade cryolite recovery plant and its production capacity. The curve was derived by using in-house figures for the capital cost of a cryolite recovery facility in 1968. The plant capacity is 8,000 tons of standard grade cryolite per year. The costs were escalated to 1970. The cost of

FIGURE 3.9

PROCESS BLOCK FLOW DIAGRAM FOR STANDARD GRADE CRYOLITE RECOVERY

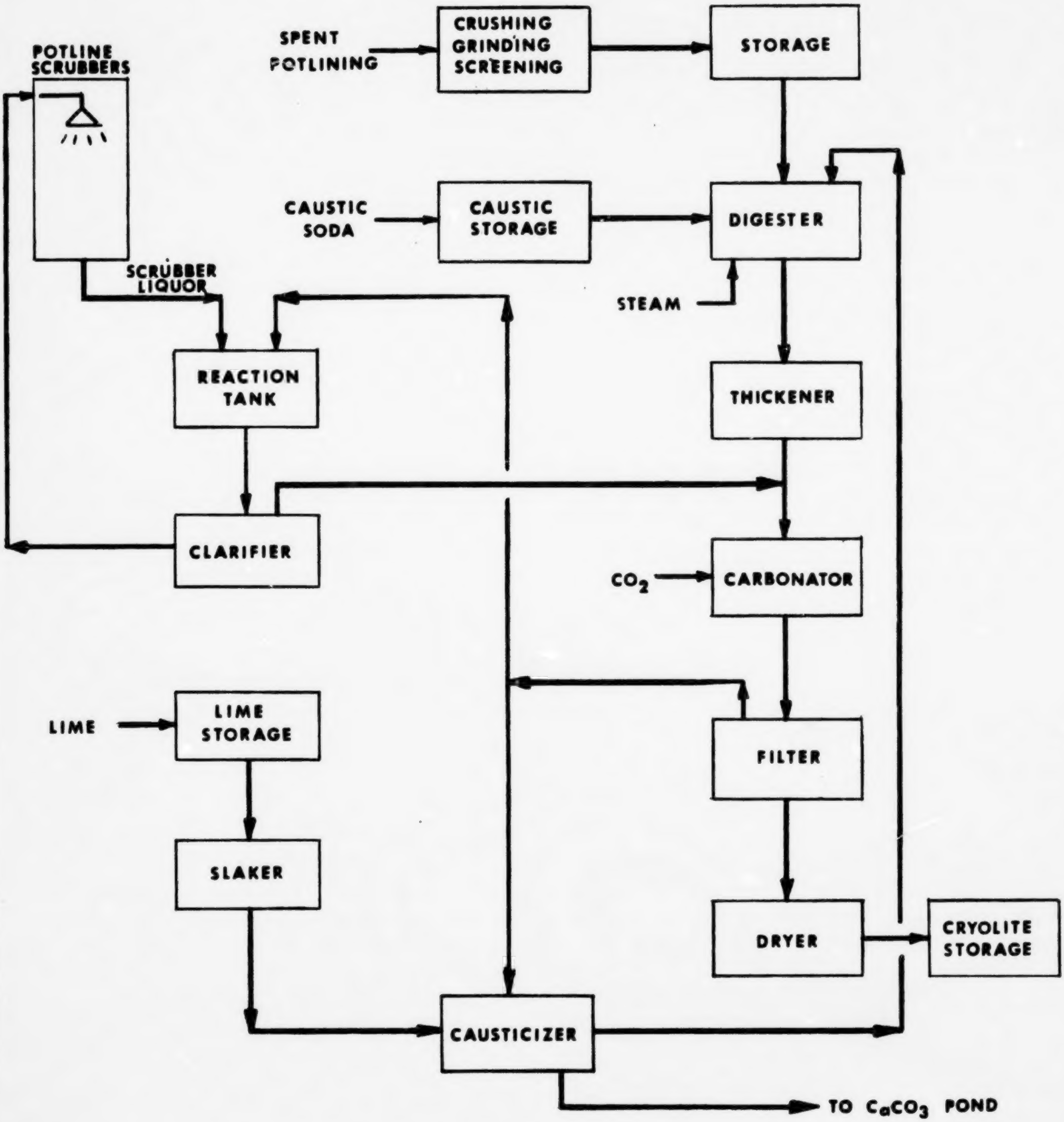
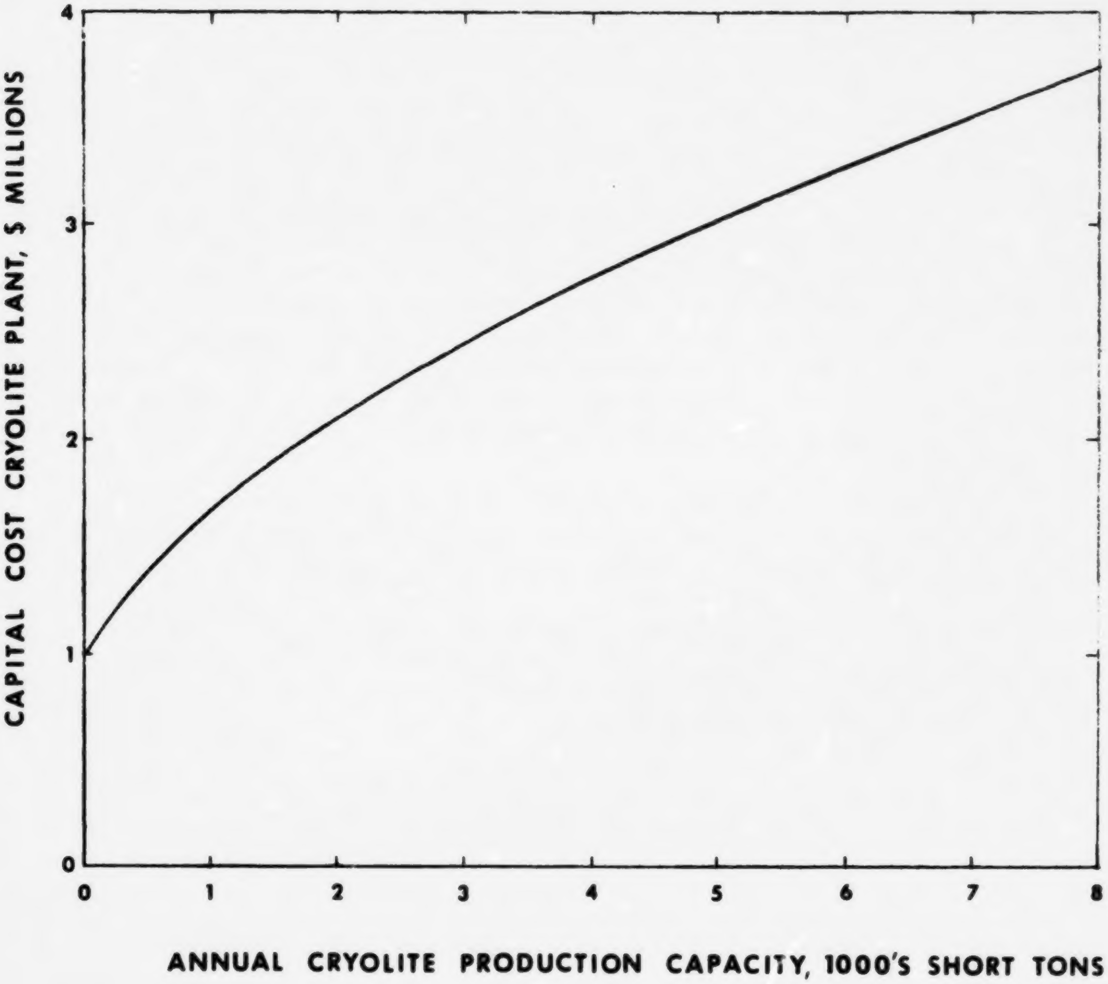

POTLINE SCRUBBERS
SPENT POTLINING
CRUSHING GRINDING SCREENING
STORAGE
CAUSTIC SODA
CAUSTIC STORAGE
DIGESTER
SCRUBBER LIQUOR
STEAM
REACTION TANK
THICKENER
CLARIFIER
CO_2
CARBONATOR
LIME
LIME STORAGE
FILTER
SLAKER
DRYER
CRYOLITE STORAGE
CAUSTICIZER
TO $CaCO_3$ POND

FIGURE 3.10

CAPITAL COST CRYOLITE PLANT
VS
PRODUCTION CAPACITY



SOURCE - SINGMASTER & BREYER ESTIMATE

the plants with less than 8,000 tons per year capacity were calculated by using the following equation:

$$\text{Capital Cost} = \text{Constant} + X\left(\frac{Y}{8000}\right)^{0.6}$$

where: Constant = Engineering cost and fixed indirect construction costs.

X = Labor and material costs to construct a plant of 8,000 tons per year capacity

Y = Capacity of other plants, tons per year

Figure 3.11 shows the unit production cost of cryolite for plants of varying capacity. The double scale on the X-axis shows the relationship between the capacity of the cryolite recovery facility and the production of a reduction plant that would be necessary to supply the spent pot lining and scrubber liquor to sustain the operation of the cryolite facility. Production costs include labor: maintenance and services; raw materials; taxes and insurance; and depreciation and interest.

Labor, maintenance, and service costs were estimated from the actual experience of an 8,000 ton per year plant.

Raw material costs were calculated from the tonnages involved and the market price of the materials. Spent pot lining was priced at $180 per ton of contained fluorine.

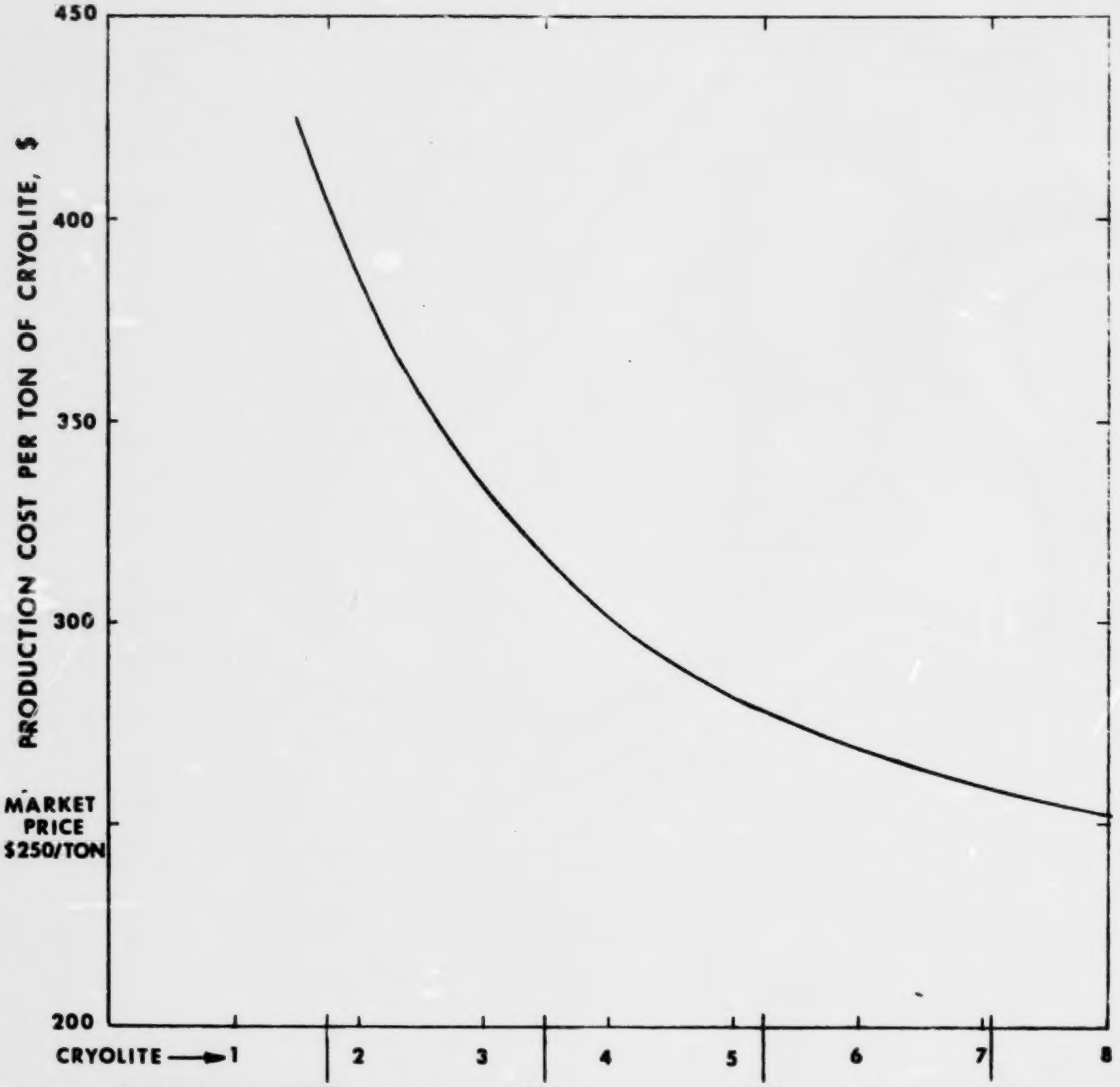
Taxes and insurance were estimated at two percent and depreciation and interest at sixteen percent of capital costs.

3.7 Heat Generation

All aluminum smelters include a heat generating plant; a few also generate electric power. All but one of the United States plants normally burn natural gas in their boilers, a fuel which emits negligible pollutants. The one exception is a small powdered coal unit, 33×10^6 Btu per hour, which is used only for peak winter heating.

FIGURE 3.11

PRODUCTION COST OF CRYOLITE
VS PLANT SIZE



SOURCE - SINGMASTER & BREYER ESTIMATE

Among the 31 heating units reported in the Industry Questionnaire, the unit sizes range from 4 x 10^6 to 117 x 10^6 Btu per hour with a weighted average about 30 x 10^6 Btu per hour. None uses control equipment for emissions other than stacks ranging from 35 to 175 feet tall.

Although most smelters purchase their electric power from utility companies, one generates power with gas-fired steam boiler-turbines and gas turbines and a few produce power from gas-fired piston engines.

Reference - Section 3

3.1/ Garcia, A. F., and Lewis, R. H., with Reese, K. M., editor, "Aluminum--Light Metals King", Industrial and Engineering Chemistry 47 (10):2066-2072 (October 1955).

Table of Contents

Section 4

4.0 Sources and Characteristics of Effluent Releases

4.1 Potline Effluents

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    Gaseous Composition

  4.1.2 Factors Influencing Effluent Generation

4.2 Carbon Plant Effluents

4.3 Bake Plant Effluents

4.4 Cast House Effluents

4.5 Other Effluents

4.0 Sources and Characteristics of Effluent Releases

The airborne effluents from primary aluminum reduction plant operations include dusts of carbon and alumina from materials handling and preparation, and particulates and gases evolved from potlines, anode bake furnaces and cast houses. The greater quantity (and potentially most damaging) are evolved in the actual electrolytic reduction process at the potline. An understanding of the operations causing the release of the various kinds of pollutants, and the identification of sources, provides a basis for consideration of abatement by control over process variables and for the selection of effective pollutant removal equipment. The following paragraphs discuss factors which influence the production of effluents.

4.1 Potline Effluents

The quantities and composition of potline effluents vary within wide limits among modern aluminum smelters, being strongly influenced by operation conditions such as temperature, bath ratio, frequency of anode effects, and method of crust breaking. Moreover, the effluent may vary with time for any given plant, due to gradual changes which may occur in potline operations.

Normal cell operation is interrupted by occasional anode effects, cell working to introduce alumina feed, periodic tapping of molten aluminum and in the case of prebake cells, the periodic changing of anodes.

According to one investigator, the normal fluoride evolution from a crusted-over cell is approximately 15 pounds F per thousand pounds of aluminum produced but during an anode effect the fluoride evolution increases to approximately 378 pounds per thousand pounds of aluminum, 4.1/. Normally individual cells in this country may experience from less than one-half to two anode effects per cell day. The duration of an anode effect is dependent upon how quickly the cell operator corrects it and may range from five to fifteen minutes.

Breaking the crust of the cell for a cell working causes the fluorine evolution to rise to approximately 53 pounds per thousand pounds of aluminum. 4.1/ The duration of a cell working varies according to the size and type of the cell and whether or not the cell is equipped with automatic crust breakers. With the automatic crust breaker on a prebake cell, working is accomplished very quickly, taking only one or two minutes. For a normal size prebake cell of approximately 90,000 amperes, a manual working may be accomplished in five to ten minutes depending upon the hardness of the crust. Soderberg cells and side-working prebake cells are normally worked by means of a pneumatic crust breaker similar to a paving breaker. A working may be accomplished in approximately five minutes on a 90,000 ampere side-worked cell.

Tapping and changing anodes cause the least increase in fluorine evolution depending upon how much of the molten electrolyte is exposed.

Sulfur oxide effluents originate from the coke and pitch from which the sacrificial anodes are made.

4.1.1 Composition of Potline Effluents

A typical prebake cell effluent, derived from published information in the literature, and the Industry Questionnaire, is shown in Table 4.1. These data indicate that:

a) Roughly 25-63 pounds of particulates are released per 1000 pounds of aluminum produced, of which 10-25 percent of the weight is fluorine content.

b) Gaseous fluorine content is approximately half again the weight of fluorine contained in the particulates.

Table 4.1

Reduction Cell Effluents

Component	Quantity lb/M lb Al	
	European 1/	U.S. 3/
CO_2	1500	-
CO	250	-
SO_2	6.5	30 2/
"F" (Gas)	10.3	13.1 3/
"F" (Solid)	6.3	8.8 3/
Total "F"	16.6	22.5 3/
Total Solids	25 to 63	45.6 3/

1/ Ref. 4.2/, 4.3/, 4.4/, 4.5/, 4.6/, 4.7/, 4.8/, 4.9/

2/ Estimate based on 3 percent sulfur in anode coke.

3/ Industry Questionnaire, Weighted Average Response.

J. L. Henry, contributing to a 1962 international symposium on the extractive metallurgy of aluminum 4.2/, reviewed the nature of reduction plant fumes. The following summary of effluent compositions is based largely on this review.

Particulate Composition and Particle Size

The particulate phase of the cell effluents contains material derived from dusting of the alumina and other raw materials during the feeding operation of the cells, solid matter which originates from the volatilization of the fused salt bath, and material mechanically entrained by the air sweep over the cell surface into the collection system. The greatest portion of the airborne particulates consists of alumina from dusting; some of the alumina is formed by thermal hydrolysis of the volatized bath materials. Carbon particles result from the mechanical and electrochemical dusting of the anodes.

Other components have been identified in the particulate matter including cryolite (Na_3AlF_6), aluminum fluoride (AlF_3), calcium fluoride (CaF_2), chiolite (Na_5Al_3F14) and iron oxide (Fe_2O_3).

Particle size distribution is a principal determining factor in the particulate removal efficiency for most types of air pollution control equipment, and knowledge of the size distribution for a given pollutant may aid in estimating the removal efficiencies of alternative selections among types of removal equipment. If the fractional removal efficiency characteristic of a piece of control equipment is known and if the particle size distribution of a pollutant can be determined by the same or comparable measuring equipment used for determining the fractional efficiency, then these data may be combined to calculate an overall removal efficiency for the equipment operating on the pollutant dust in question.

Published or reported cell effluent particle size distribution data are sparse and techniques for measurement are subject to variations, even among different investigators using similar equipment, so caution should be exercised in drawing conclusions from these data or in comparing data from one source with those from another.

However, a limited amount of available information provides a basis for estimating the performance of some types of control equipment applied to potline effluents.

Reported determinations of particle size distributions of the dust and fume collected in primary effluents are plotted in Figure 4.1. Two plots are shown for prebake potlines, one reported as the average of four samples of pot emissions, the other as the average of five samples of electrostatic precipitator intake. A single plot of average samples is shown for HSS Soderberg. No comparable data have been obtained for VSS Soderberg effluents.

These plots are illustrative of the comparative size characteristics of the primary dusts from two types of cells. The slopes of these data give an indication of the range of particle sizes in the samples and the placement of the curves on the plot indicates that a substantial fraction of the prebake and HSS particulate weight is submicron, or in the range where particulate removal efficiencies of most equipment are low.

Additional particle size data are reported in Appendix 4A.

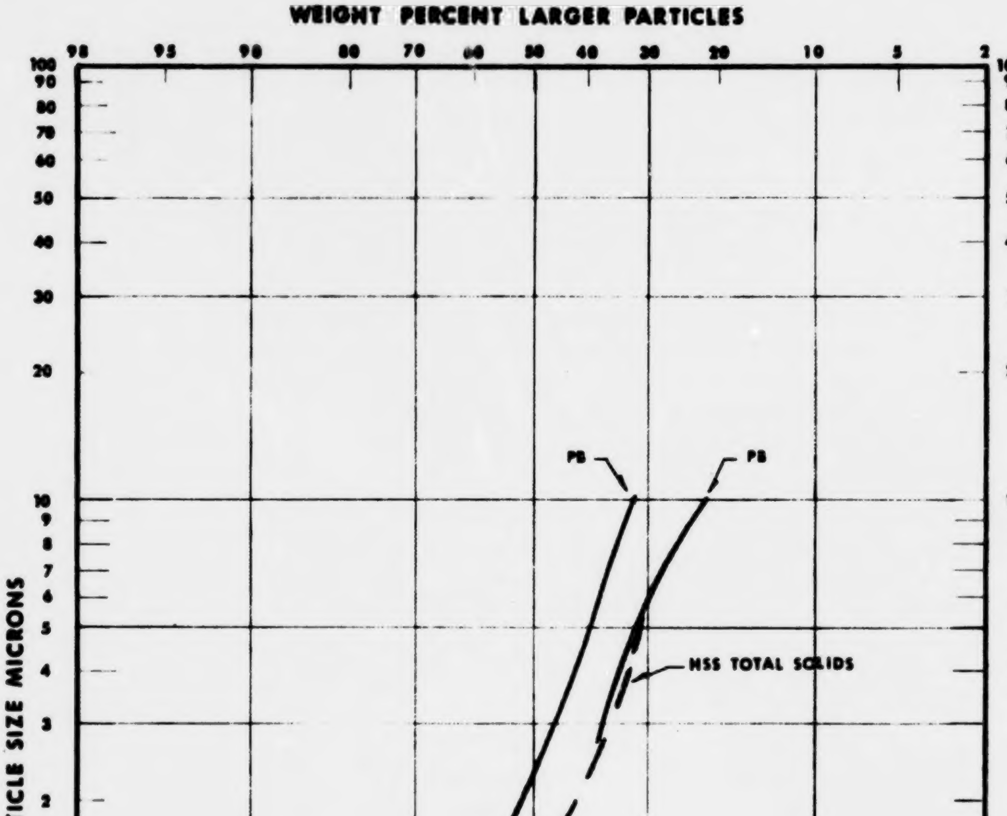
Gaseous Composition

The gaseous phase of the cell effluent, before coming into contact with air, consists principally of carbon dioxide and carbon monoxide formed by the oxidation of carbon anodes by oxygen released from Al_2O_3 on electrolysis. Although the mechanism of formation is subject to argument, the variation in volume ratio of the two gases during the normal cycle of cell operation is generally known. The ratio of CO_2 to CO decreases when the cell temperature is abnormally high and also during the periods when the anodes are polarized (anode effect). The carbon dioxide content of the unburned gases varies between 60 and 85 percent; the balance is largely carbon monoxide. Contact of the hot gases with air results in a substantial decrease in the carbon monoxide through combustion.

Other gases may be found in small amounts during cell operation. These include sulfur dioxide (SO_2), hydrogen sulfide (H_2S), carbonyl sulfide (COS), carbon

FIGURE 4.1

PARTICLE SIZE WEIGHT DISTRIBUTION
POTLINE PRIMARY EFFLUENT



INDUSTRY REPORTED DATA

disulfide (CS_2), silicon tetrafluoride (SiF_4); hydrogen fluoride (HF), and water vapor.

During the period of an anode effect, fluorocarbons are known to be produced. These consist almost entirely of carbon tetrafluoride (CF_4) together with very small amounts of hexafluoroethane (C_2F_6).

Fluorine

Henry reports that the ratio of gaseous to particulate fluoride in reduction cell fumes varies over a range of about 0.5 to 1.3. These values are given for fumes which have burned in contact with air. Weighted average data from the Industry Questionnaire indicate that this ratio is about 1.2 to 1.7 for prebake and HSS Soderberg cells and about 3.0 for VSS Soderberg cells with hydrocarbon combustors. Unburned fumes usually show a lower ratio of about 0.3, according to Henry. Burning of the hot gas-particulate mixture when it contacts air results in thermal hydrolysis of some of the particulate fluoride with the formation of additional hydrogen fluoride.

Thermal hydrolysis of volatized bath materials appears to be responsible for a substantial part of the hydrogen fluoride found in reduction cell fumes. This reaction of solid or vaporized fluorides with water vapor at elevated temperatures takes place primarily at the point where the hot gases escape through vents in the crust.

A source of hydrogen is necessary for the generation of hydrogen fluoride. Water vapor in the air is a contributor of part of this hydrogen. Other sources include residual moisture in alumina and bath raw materials and hydrocarbons in the carbon anodes.

Some gaseous hydrogen fluoride is removed from the effluent stream by interaction with the contained particulate matter. Chemical reaction is responsible for some of this pickup, while some is due to chemisorption, absorption, and adsorption.

While the determination of total fluoride content of fumes may be quite reliable, estimates of the distribution of fluoride between gaseous and particulates forms is subject to uncertainty due to such factors as the degree of thermal hydrolysis during burning of the gas and method of separation of gas and particulates during sampling.

Sulfur Oxides

The sacrificial carbon anodes of aluminum reduction cells are made from calcined petroleum coke which characteristically contains sulfur. Whereas coke with a maximum sulfur content of 2.5 percent was once readily available, it has become scarce and smelters now buy coke with as much as 5 percent sulfur. The average petroleum coke now in use may contain 3 percent.

Since this coke has already been calcined at temperatures above the anode baking temperature, the sulfur is fixed and will be released only as the anode is consumed in the electrolysis process. Depending on sulfur content of anode carbon, the SO_2 effluent may range from 15 to 50 pounds per 1000 pounds of aluminum produced.

Soderberg Effluents

The effluents from Soderberg cells have, in addition to the constituents mentioned above, the characteristic of containing the hydrocarbons evolved by the baking of the anode paste in the cells. The presence of these hydrocarbons, which are in gaseous form at the cell operating temperatures, complicates in some degree the emission control problems associated with Soderberg cells. If they cannot be converted by combustion to stable gaseous compounds the hydrocarbons will condense to tarry compounds which are difficult to handle and remove from the gas stream. As will be noted in a later section, the collection and combustion of these materials is practical with the VSS Soderberg cell, but not with the HSS Soderberg cell. In the latter case the problem of tar separation becomes somewhat similar to that encountered in prebaked anode furnace plants, where similar tars are present in the effluents.

4.1.2 Factors Influencing Potline Fluorine Effluent Generation

J. L. Henry reported 4.2/ on experimental work which established correlations between three cell operating parameters and effluent production for a 10,000 ampere laboratory experimental prebake type aluminum reduction cell. It was shown that increasing bath ratio (NaF/AlF_3), increasing alumina content of the bath, and decreasing temperature all tend to result in a decrease in the fluoride content of cell effluent. Table 4.2 summarizes the findings of these tests.

Table 4.2

Experimental Effect of Three Operating Variables on Fluoride Effluent

Range of Variables			
Bath Ratio	Alumina Content	Temperature	Fluoride Effluent
(1.44 to 1.54)	4%	975°C	31% Decrease[1/]
1.50	(3% to 5%)	975°C	20% Decrease[1/]
1.50	4%	(982 to 972°C)	24% Decrease[1/]

[1/] Within range of variable denoted by ( ).

Henry calls attention in his paper to the fact that "determination of the effect of operating variables on the fluoride emission from electrolytic reduction cells is difficult to accomplish with a high degree of certainty. This is true even with small-scale experimental cells operated by research personnel. It appears from the work reported here, however, that cell temperature, bath ratio, and alumina concentration are the most important variables affecting total fluoride emission".

The absolute relationships reported by Henry may not hold for full-scale cell operation.

4.2 Carbon Plant Effluents

Aluminum reduction cell anodes and cathodes are made from anthracite and/or petroleum coke, bonded by pitch and baked to form solid carbon masses. The preparation of the carbon materials, consisting of crushing, grinding, classifying, blending of carefully sized fractions, and mixing with pitch binder, is carried out in the green mill. In all but a few cases, this carbon plant operation is carried out on the reduction plant site, the exceptions being plants utilizing prebaked anodes and cathode blocks which are shipped to the plant already fabricated.

The effluents from these operations consist of coke and coal dusts and fines generated by comminution, screening, and materials handling. Control is practiced to maintain plant housekeeping and industrial hygiene standards. Effluents are generally coarse particulates, easily controlled by collection to bag houses, and do not constitute a significant air pollution problem beyond the boundaries of an aluminum reduction facility.

Volatile hydrocarbon fumes are generated to a limited extent by the paste mixing operation in which the hot pitch binder is added to the dry materials. This effluent is usually vented directly to atmosphere. In some operations, however, these fumes are partially removed from their gas streams by using a wet scrubber.

4.3 Bake Plant - Effluents

For plants using prebaked anodes the carbon paste is pressed to green forms and baked for extended periods, during which time effluents are generated and released.

Bake plant effluents may include products of firing combustion, burned and unburned hydrocarbons derived from the heating and carbonizing of the paste binder pitch, SO_2 and SO_3 derived from the carbon paste materials, and fluorine. The source of the latter is recycled anode butt scraps which carry absorbed or adherent bath materials back into the anode cycle.

Little information has been obtained or published concerning the quantitative amounts of bake plant effluents. A very limited amount of testing has been carried out on baking emissions. The order of magnitude of the problem is indicated in Table 4.3, supplied as an average by a multi-plant aluminum producer. It is reported that total F effluents can be maintained at less than 0.4 pound per ton of aluminum produced by exercising particular attention to cleaning the spent anode butts of adherent bath before they are crushed for recycle.

Table 4.3

Anode Baking Ring Furnace Emissions 1/

Flow Rate, cfm	75,000 - 184,000
Stream Loading, gr/cf	
Total Solids	0.021 - 0.10
HF	0.003 - 0.03
Pitch Condensate	0.01 - 0.30
Quantities, lb/1000 lb Al	
Total Solids	1.0 - 5.0
Hydrocarbon	0.25 - 0.75
Total F	0.15 - 0.75
Sulfur	0.35 - 1.0

1/ While the direct fired ring furnace has been the normally used type for prebaked anodes, attention has been given to the development of continuous tunnel kilns for this purpose. Combustion conditions are significantly different and zonal temperature control closer, with one result being that the above emission levels may be reduced by factors of 0.01 in total solids and 0.02 in hydrocarbons, fluorine, and sulfur.

4.4 Cast House Effluents

Cast house operations include the receipt of molten metal in tapping crucibles from the potlines, transfer to holding furnaces or casting in large sows for later remelt, fluxing for the removal of impurities, alloying, and casting into ingots or billets. Effluent releases from these operations consist largely of fluxing fumes, periodically evolved.

Furnaces are usually gas-fired, and in themselves present no potential pollution problem.

Blended metal from the holding furnaces can be gas-fluxed or salt-fluxed for the removal of certain impurities such as oxides, bath electrolyte, or gas inclusions and the skimmings, or dross, subsequently treated for metal recovery.

Gas fluxing involves the bubbling of chlorine, nitrogen, argon, helium, or mixtures of chlorine with any of the inert gases, through the molten metal in the holding furnace. Salt fluxing, in which the salt is added to the bath surface, may utilize hexachlorethane, aluminum chloride, and magnesium chloride. In all cases where chlorine or chlorine compounds are used for fluxing, copious quantities of fumes are evolved, which must be collected and removed from the working area and may or may not be treated. The fume is primarily aluminum chloride which, in the presence of atmospheric moisture, may hydrolyze to HCl and Al_2O_3. If a melt is overfluxed, free chlorine may evolve. Traces of fluorine may be present in the fumes, originating with electrolyte impurities fluxed from the metal.

4.5 Other Effluents

The handling of dry bulk materials, alumina, cryolite, and fluorspar is accompanied by dusting at transfer points. These particulate effluents are normally an industrial hygiene problem but may create an air pollution problem. Normally they are collected at the points of evolution and returned to the handling systems.

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5.0 Technology of Emission Control

The effective control of effluents from an aluminum smelter potline involves attention to:

a) Operating conditions in the cells,

b) Collection of effluents from the cells,

c) Removal of pollutants from the collected effluent streams.

Anything which can be done to reduce the quantity of noxious effluent from the process will improve the ultimate emission picture from a pollution control system. Also, since overall control efficiency is the product of collection and removal efficiencies, a highly effective scrubber system, for example, loses its value if a substantial fraction of the effluent escapes the collection system. All three factors: operating conditions, collection efficiency, and removal efficiency should be treated carefully to achieve optimum control over plant emissions.

5.1 Effect of Potroom Operating Conditions

Section 4.1 describes several conditions in reduction cell operations which give rise to higher than average effluent production and careful control over cell operation can minimize potline effluents. Specifically, the following measures may be used to achieve these ends.

5.1.1 Suppression of Anode Effects

During an anode effect the cell voltage differential rises from its normal 4.5-4.8 volts to 40-60 volts and the line current is reduced by from three to five thousand amperes. The net effect is that the power input to the cell increases more than tenfold. The entire power increase is converted into heat, which in turn raises the temperature of the cell electrolyte. At the higher cell temperature, the fluorine evolution is increased. For the anode effect effluent rate compared with quiet cell operation, Less and Waddington 5.1/ found a 27-fold increase in solid F and a 2.7-fold increase in HF. Depending on the promptness with which the cell operator reacts, this anode effect may last from three to fifteen minutes. Occasionally cell operators will deliberately allow anode effects to continue in order to soften an unusually hard crust. Automatic crustbreakers help to minimize the need for this practice. In normal cell operation, with manual crust breaking, the frequency of anode effects is from less than one-half to as many as six anode effects per cell day.

Placing cells on an anode effect suppression system, that is, scheduled workings of the cell in order that the alumina content of the electrolyte is replenished before it falls below the concentration causing the anode effect, can reduce the frequency of anode effects to the range of one-half to one anode effect per cell day. The newer computer controlled potlines may operate almost free from anode effects.

5.1.2 Reduced Bath Temperature

The higher the bath temperature, the more will the bath salts vaporize and be carried into the cell effluents. Normal operating temperatures for cells with a bath ratio of approximately 1.40 are between 970 and 980 degrees centigrade. This relatively low operating temperature is near the freezing point of the electrolyte and close attention by cell operators is necessary to prevent the cell from becoming too cold, or "mucking up". A cold cell is corrected by increasing the cell voltage and allowing the electrolyte to increase in temperature. Abnormal or "sick" cells operate at temperatures in excess of 1000°C and sometimes they do not crust over. Under these conditions, the high temperature molten electrolyte is exposed and there is a large increase in volatilization of bath salts with a corresponding increase of fluorine in the cell effluents. Operation of cells at the lowest possible temperature to minimize fluorine effluents requires trained, conscientious cell operators, or computer control.

While the temperature of the cell may be lowered by the additions of lithium salts to the electrolyte, lowering its freezing point, the net benefit of these additions is the subject of controversy. One overseas investigator 5.2/ reports, among other advantages, a substantial decrease of fluorine losses in waste gases which resulted in a reduction of fluorine emissions. In this country experiments undertaken by a major producer, were reported to have demonstrated quite the contrary of the referenced conclusions.

The electrolyte system is complex, and electrolyte conditions which reduce fluorine emissions from the molten bath but which simultaneously destroy the ability of the bath to crust over and carry a cover of alumina may result in a net increase in cell emission; the alumina cover intercepts a substantial quantity of fluoride and returns it directly to the molten bath.

5.1.3 Hood Maintenance and Operation

Most aluminum smelters which have pollution control equipment designed to achieve high overall control efficiencies depend on a primary hooding system to collect most of the cell effluent and conduct it to removal equipment. Any effluents which escape the primary collection systems are exhausted through roof monitors with or without treatment. Overall control efficiency is limited by the collection or hooding efficiency with which cell effluents are drawn into the primary control system. Present cell designs, regardless of how well enclosed or shielded they may be, do not achieve 100 percent hooding efficiency because the shields need to be opened for cell working, at least for anode replacement in the case of prebake lines, and for metal tapping in all lines. However, careful attention to the design and construction of hoods, and strict insistence that potroom operators keep shields in good repair and that they open or remove them no more than necessary, will contribute significantly to improved pollution control.

Some potlines are provided with means for increasing the air flow into the primary collection system at individual cells when hoods need to be opened. This contributes strongly to high collection efficiency and permits a realization of economy of low air flow when the cell is properly enclosed.

In recognition of the particular importance of hooding or collection efficiency, one operator of prebake potlines makes a special effort to aim for 100 percent, and estimates a realization of 95 to 97 percent based on total F effluent. The design of this system incorporates provision to double the flow rate on any cell which is opened for working, tapping, or anode changing. Older design cells and those without dual air flow provisions usually do not achieve these high collection efficiencies; in fact they may average ten or more percentage points lower.

5.1.4 Mechanization and Computer Control

Mechanization of crust breaking and cell feeding allows the cell operators time to maintain close watch over the operating cells and to control them within narrow temperature ranges. The overall effect is lower average operating cell temperature, fewer and briefer anode effects, and a reduction in the fluorine content of cell effluent gases compared with normal manual cell operation.

Full mechanization of reduction cells makes it possible to apply computer control which incorporates the frequent scanning of operating variables on each cell and the triggering of automatic corrective action for any variation that is outside set operating limits. Such control makes it possible for all cells in a potline to be operated at the lowest practical temperature and with nearly complete freedom from upsets caused by anode effects. Cell feeding and crust breaking operations can be cycled in response to the needs of individual cells, and the number of abnormal or "sick" cells usually associated with manual potline operation can be reduced. Variations in the cell operation occasioned by having different shift personnel tending the cells over the 24-hour period are largely avoided.

Many plants are developing various degrees of computer control in combination with mechanization. Although full automation has not yet been satisfactorily accomplished, several potlines are approaching this goal on an experimental basis.

5.1.5 Effect of Ancillary Operations

The bake plant at prebake anode aluminum smelters releases effluents which are partially subject to control through provisions in operating practice. The bake plant effluents present primarily a smoke abatement problem resulting from tars and volatile hydrocarbons released from the pitch binder in the baking operations. Other effluents are SO_2 and HF. Most of the effluent SO_2 derives from the sulfur content of the pitch and coke used in the manufacture of coherent anode blocks. By using low sulfur pitch and coke, effluent SO_2 may be held to a minimum. It should be noted that low sulfur pitch and coke are becoming increasingly difficult to obtain.

HF gas in bake plant effluents comes from bath material adhering to anode butts which are recycled in the manufacture of new anodes. Special care in cleaning the butts before crushing will reduce F effluent to about one quarter the quantity experienced when adherent cryolite is simply knocked off the butts at the potroom prior to sending them to the anode plant.

5.2 Effluent Collection Systems

Effective control of aluminum potline effluents requires first that they be collected for treatment in removal equipment. Three types of collection systems are in use, each having certain advantages over the others for particular applications.

5.2.1 Roof Monitor Collection Systems

Many European reduction plant potlines and a few prebake potlines in the United States are designed to pass all airborne effluents through pollutant removal equipment located in roof monitors or ducted from collection points at the tops of the potline buildings. All potline effluent and all normal room ventilation air is intended to pass through the collection and removal equipment.

Although collection efficiency might be assumed to be 100 percent in this scheme, deficiency in the design of the provisions for air intake to the buildings may bring about a reduction in the collection efficiency. Some potline buildings have openings in the side walls at working floor level through which ventilation air enters as shown in Figure 5.1. This air is supposed to sweep past the cells and up through the roof monitor collection system, but adverse winds may blow through the buildings in such a way as to carry potline effluents out through some building wall openings, thus short circuiting the collection system and reducing its efficiency.

FIGURE 5.1

ROOM COLLECTION SYSTEM SIDEWALL ENTRY

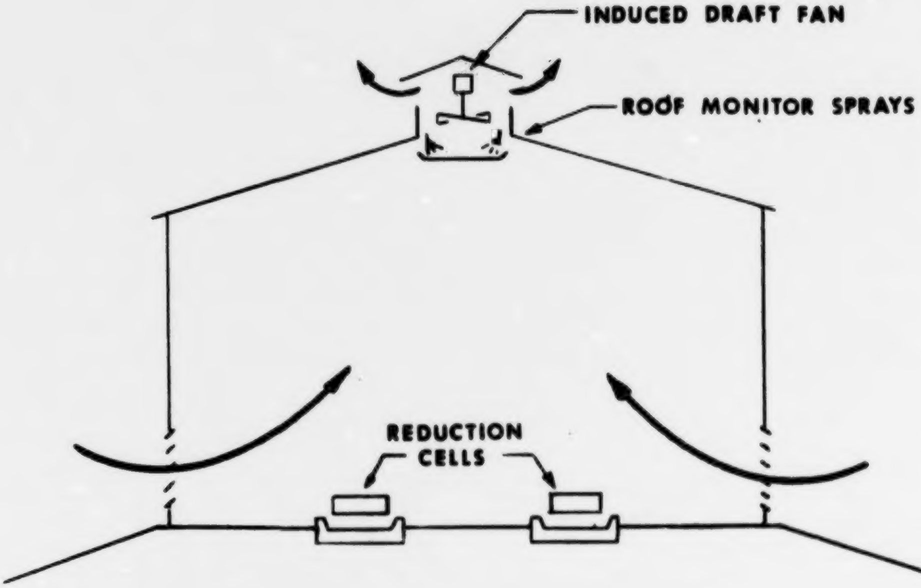
INDUCED DRAFT FAN
ROOF MONITOR SPRAYS
REDUCTION CELLS

FIGURE 5.2

ROOM COLLECTION SYSTEM BASEMENT ENTRY

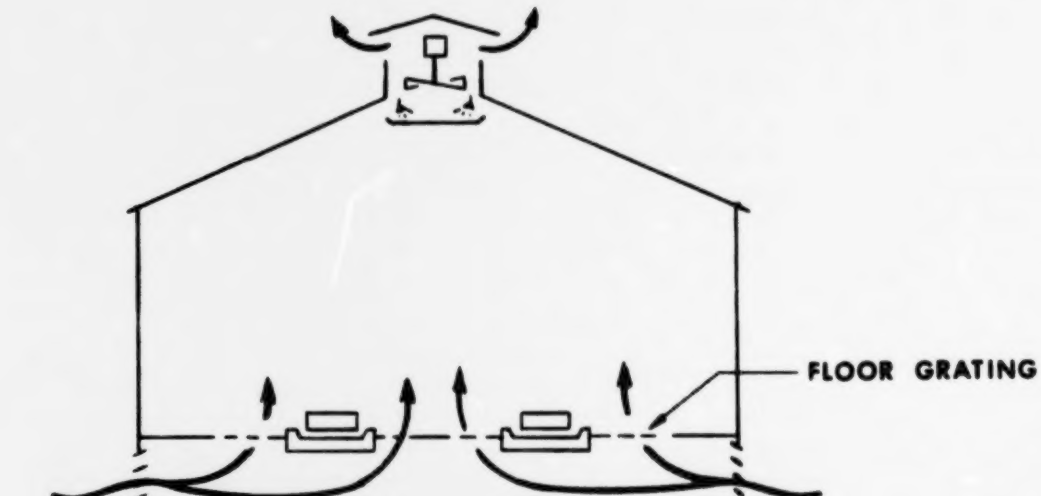
FLOOR GRATING

Figure 5.2 shows a building arrangement which helps to avoid this short circuiting of the collection system. Fresh air is drawn into the building below the working floor level and is allowed to pass up through gratings past the cells to the monitor collection system. Although sub-floor intakes may make the collection virtually 100 percent efficient, all roof monitor collection systems suffer the disadvantages that very large quantities of ventilation air must be handled, 30,000 to 60,000 cfm per cell.

5.2.2 VSS Soderberg Primary Collection System

Soderberg cells utilize an anode consisting of a rectangular container, open at the top and bottom, suspended above the cell, into which carbon paste is fed at intervals, becoming baked by the heat of the cell as it gradually descends in the container. This baking of the carbon paste releases substantial quantities of hydrocarbon gases and fumes which may interfere with proper operation of pollution control equipment.

The VSS or vertical spike suspension Soderberg design utilizes steel pins driven into the anode vertically from the top to conduct the electric current from the anode bus into the anode. These pins are removed from the anode by withdrawing them from the top before they are carried by the anode into the bath zone. Since no side channels are needed as in the HSS Soderberg, it is possible to install a permanent gas collecting skirt around the bottom of the anode which is sealed to the electrolyte crust by a blanket of alumina. (See Figure 3.5). Most gases and particulate effluents pass into the skirt enclosure and to a gas collection system.

This system has the advantage of very low air dilution and sufficiently high hydrocarbon concentration that the effluent gases may be burned; most of the hydrocarbons, both gaseous and particulate, and much of the CO, is oxidized to CO_2 and water vapor. The effluent gas leaving the burner is low in hydrocarbons and may then be treated in a manner similar to prebake cell effluents.

One typical VSS Soderberg collector passes about 20 scfm of cell gas and 200 scfm of secondary combustion air into each of two burners on the collecting skirt.

The discharge from the burners, about 400 scfm per cell, passes into ducts for transport to pollutant removal equipment.*

Skirt and burner type systems on VSS Soderberg cells collect most of the cell effluents during approximately 95 percent of the time when the cell is operating without disturbance of the crust and the alumina seal. When the crust is broken, the alumina seal falls into the molten electrolyte and some gaseous and particulate effluents escape the collection system and pass into the room atmosphere for subsequent discharge through the roof monitor. Any hydrocarbon effluents escaping from the top of the anode pass directly into the room atmosphere and also are discharged through the roof monitor.

Average fluoride collection efficiencies for VSS Soderberg potline systems have been reported to range from 70 to 95 percent.*

5.2.3 Prebake and HSS Soderberg Cell Hooded Collection Systems

The physical arrangements of prebake and HSS Soderberg reduction cells lend themselves to hooding or enclosures connected with duct systems to collect most of the cell effluents and deliver them to primary pollutant removal equipment. (See Figures 3.3 and 3.4). These systems characteristically draw 2000 to 8000 cfm of air into the hoods at each cell. The concentrations of cell effluents in the entraining air are intermediate between those found in the VSS Soderberg skirt and burner system and the European designs which permit all effluents to mix with the building ventilation air.

The effectiveness of the cell enclosure primary collection system depends essentially on three factors.

a) Hood Designs - Designs which leave a minimum of leaks to the potroom and which limit the exposure during crust breaking and anode changing operations will outperform poorer designs. Center working pots in which crust breaking and alumina charging operations take place in the middle between rows of anodes, especially pots with cell mounted automated crustbreakers, permit tight hood designs which need be opened only occasionally to change anodes or to remove molten aluminum from the cells.

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* Industry Questionnaire Response

b) Operator Care - Careful supervision of potroom operating personnel to ensure that they maintain shields in good repair and close hoods promptly after working cells will reduce emission to the cell room and improve overall collection efficiency.

c) Air Flow Rate - Increasing the air flow rate into primary collection systems reduces the tendency for effluents to escape through openings in cell hoods and improves the collection of dust and gases during periods when the hoods are open for cell working, alumina feeding, or anode replacement. A dual volume exhaust system permits an increased exhaust rate to provide a greater collection efficiency when hoods are removed.

Aluminum smelters in the United States have reported primary collection efficiencies for hooded prebake and HSS Soderberg potlines to range from 71 to 98 percent*, averaging in the 90's for prebake cells and somewhat lower for HSS Soderberg cells.

5.3 Emission Control Techniques

The emission control problems of the primary aluminum reduction plant are a result of the effluent conditions described in the previous section, and are concerned with the removal of particulates and of HF gas from the stream in which they occur.

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* Industry Questionnaire Response

5.3.1 Removal Mechanisms

Particulates

Particulates include solid particles of carbon, alumina and bath materials, tar fogs (hydrocarbons) and inorganic fumes. Their removal from gas streams may be accomplished by inertial segregation from the gas phase, by collection in a liquid phase, by interception on a porous medium, or by segregation through electrostatic agglomeration and attraction.

These mechanisms are affected in greater or lesser degree by the size particulate to be removed. Particulates larger than about two microns may be separated from gas streams by gravitational or centrifugally induced forces.

Collection of particles into a liquid medium, as by wet scrubbing, is effected by inertial impaction, interception, and diffusion, depending upon the particle size and its inertial behavior. The inertial impaction mechanism assumes that particles have sufficient mass or inertia to leave the flow streamlines and strike a liquid surface around which the streamlines are bending. The interception mechanism assumes that the particles have size, but no mass, and follow the gas streamlines so that a particle is collected only when the gas streamline is closer to an obstruction than half the diameter of the particle.

Collection of submicron particles which lack sufficient mass to exhibit significant inertia and are too small to be collected by interception may be collected by a diffusion mechanism that visualizes the particles as moving about in the gas in a manner characteristic of the thermodynamic behavior of gas molecules.

Interception by a porous medium involves the mechanical entrapment of the particles in the interstices of built up layers of the medium. These interstices may become submicron in size.

Electrostatic attraction among charged particles and between charged particles and a collecting surface may effect the agglomeration and capture of fine particulates. Consideration of their electrostatic properties with respect to specific dusts may be a factor in the selection of filter fibers. Electrostatic attraction between effluent feed particles and the bed mass is a factor in fluid bed agglomeration and capture.

In electrostatic precipitation, forces acting on electrically charged particles in the presence of an impressed electric field are utilized to remove solid or liquid particles down to and including submicron sizes. The particulates are attracted to and retained on the collection electrode and are removed either by intermittent rapping or continuous irrigation.

Tar fogs generated by volatilization from Soderberg anodes present added problems in particulate emission control. The wet scrubbing mechanisms apply to their capture; however, particle reentrainment may occur because tars resist wetting and thus reduce the effective removal. Where these fogs are in relatively concentrated form, as from VSS Soderberg potlines, they may be burned by self-supporting combustion. If the effluent gas stream is dilute, as from HSS Soderberg potlines, pitch mixers, or anode bake plants, self-supporting combustion is not possible. In these cases agglomeration of the tar fog may occur, together with condensation of hydrocarbons forming sticky deposits which interfere with collection devices and removal mechanisms.

Gaseous Fluoride

The principal gaseous pollutant in potline and bake plant effluent streams is fluorine as HF, and the control mechanism for its removal is absorption in a selected liquid solvent or adsorption on the surface of a selected solid. The HF gas molecules to be removed must diffuse from the bulk gas stream to the surface of the liquid or solid, pass the phase boundary, and in the case of the liquid solvent, diffuse into the liquid phase.

In liquid absorption there is a tendency for dissolved molecules to migrate back through the interface and escape to the gaseous phase (a measure of this tendency to escape is vapor pressure). This back pressure effect is reduced by use of an alkaline solution which reacts with the dissolved HF molecules to form an ionic solution. Effective vapor pressure and the contact area control the removal efficiencies.

In dry scrubbing, the mechanism of adsorption is controlled by the reactivity of the adsorbent and the surface area available for gas-solid contact, the intimacy of contact and, to a lesser extent, the contact time.

5.3.2 Removal Equipment

Table 5.1 summarizes the removal equipment considered for emission control of the different types of effluent streams in the aluminum industry. The table includes the devices which are used singly or in combination by the domestic producers, and by some of the foreign plants. It also includes equipment which has been, or is known to be under application development, as well as some which experience indicates to have potential application.

Reportable performance and corresponding operating parameters of control equipment items in current use and considered applicable are summarized in Tables 5.2a through 5.2d, presented by type of effluent control duty. These data provide the basis for the model systems used in the analyses of Sections 8 and 9.

Details concerning the individual types of equipment and their appropriate applications are discussed in the following paragraphs.

a) Burners

The burners on the VSS Soderberg cells, previously noted and illustrated in Figure 3.5, assist in the control of cell effluents by converting hydrocarbons to CO_2 and water vapor. When the cell is operating normally, burners maintain continuous flame. However, irregularities in operation can result in a flame-out. Without the use of igniters or a satisfactory manual ignition program, from 5 to 10 percent of the burners of a potline may be out at any time, giving rise to unburned hydrocarbons in the potline effluent gas stream entering the removal equipment.

The important combustion variables include effluent tar composition and concentration, and air supply to the burner. The latter is determined by the size,

Table 5.1

CONTROL EQUIPMENT CONSIDERED FOR THE PRIMARY ALUMINUM INDUSTRY

	PREBAKE POTLINES			VSS POTLINES		HSS POTLINES		ANCILLARY PROCESSES			
	Prim. no Sec.	Sec. with Prim.	Sec. no Prim.	Prim. no Sec.	Sec. with Prim.	Prim. no Sec.	Sec. with Prim.	Bake Plant	Dry Mtls.	Paste Mix	Cast House
Burner	-	-	-	A	-	-	-	-	-	-	-
Incinerator	-	-	-	-	-	-	-	-	-	-	-
Multiple Cyclone	A	-	-	A	-	-	-	-	A	-	-
Baghouse Filter	-	-	-	-	-	-	-	-	A	-	-
Fluid Bed Dry Scrubber	A	-	-	A*	-	-	-	-	-	-	-
Coated Filter Dry Scrubber	A	-	-	-	-	-	-	-	-	-	-
Injected Alumina Dry Scrubber	A*	-	-	A*	-	-	-	-	-	-	-
Dry Electrostatic Precipitator	A	-	-	A*	-	-	-	A	A	-	-
Wet Electrostatic Precipitator	-	-	-	A	-	C	-	C	-	B	B
Spray Tower	A	-	-	A	-	A	-	A	-	A	-
Spray Screen	-	A	A	-	A	B	B	B	-	-	-
High Pressure Spray Screen	B	-	-	B	-	D	-	B	-	B	-
Wet Centrifugal Scrubber	-	-	-	D	-	-	-	-	-	-	-
Venturi	-	-	-	A	-	D	-	C	-	A	B
Chamber Scrubber	A	-	-	B	-	B	-	-	-	-	-
Wet Impingement Scrubber	-	-	-	-	-	-	-	-	-	B	-
Cross Flow Packed Bed	B	-	A	B	-	C	-	-	-	-	-
Floating Bed (Bouncing Ball)	A	-	B	A*	A*1/	A	-	B	-	B	A
Sieve Plate Tower	-	-	-	A*	-	-	-	-	-	B	-
Self-Induced Spray (Bubbler)	B	-	-	A	-	B	-	A	-	B	-
Vertical Flow Packed Bed	A	-	-	A	-	-	-	-	-	B	-

Prim.	Primary collection stream.
Sec.	Secondary or potroom system.
A	In current use in the United States.
A*	In current use outside the United States.
A*1/	Used in one foreign plant. Not considered economically feasible in the United States.
B	Considered feasible but not known to be in use.
C	In development stage.
D	Superseded by other equipment.
-	Considered not feasible, economically and/or technically.

Table 5.2a - EQUIPMENT REMOVAL EFFICIENCIES -
PREBAKE POTLINES

In Current Use	Efficiencies Derived from Reported Data[1]		Operating Conditions	
Primary Control	Particulate	HF	HP/Mcfm[2]	Gal/Mcf
Multiple Cyclone	78	-	0.8-1.6	-
Fluid Bed Dry Scrubber System	98	99	4.4	-
Coated Filter Dry Scrubber [3]	98	76-92	1.5	-
Injected Alumina Dry Scrubber*	98	98	2.2	-
Dry Electrostatic Precipitator	89-98	-	0.3-0.7	-
Spray Tower	80 [3] [4]	89-98	0.4-0.9	1.7-10
Floating Bed Scrubber	80	98	1.9	18
Chamber Scrubber	85	88	1.0	5
Vertical Flow Packed Bed	85	66	0.7	5
Secondary (No Primary)				
Spray Screen	45 [4]	93 [3]	0.2	1.3-10
Cross Flow Packed Bed (3 ft.)[5]	84 [4]	99	0.5	10

Applicable	Estimated Efficiencies		Operating Conditions	
Primary Control	Particulates	HF	HP/Mcfm[2]	Gal/Mcf
Cross Flow Packed Bed (5 ft.)	87	98	1.5-1.8	10+
Self-Induced Spray	65	96	3.3	6-10
Venturi	96	99	9-10	5-10
High Pressure Spray Screen [3]	93	98	8-12	28-42
Secondary (No Primary)				
Floating Bed Wet Scrubber	75	87-95	0.3-1.0	3-10
Secondary (With Primary)				
Spray Screen	25	80	0.2	10

[1] Footnotes follow Table 5.2d

* Denotes foreign application

Table 5.2b - EQUIPMENT REMOVAL EFFICIENCIES -
VSS SODERBERG POTLINE EFFLUENTS

In Current Use	Efficiencies Derived from Reported Data[1/]*		Operating Conditions	
Primary	Particulate	HF	HP/Mcfm[2/]	Gal/Mcf
Burners	-	-	-	-
Multiple cyclones	40-50	-	1.6	-
Fluid Bed Dry Scrubber[7/]*	98 [4/]	99	4.4	-
Injected Alumina Dry Scrubber[3/]*	98 [4/]	98	2.2	-
Dry Electrostatic Precipitator*	98 [4/]	-	NA	-
Wet Electrostatic Precipitator	90-99	-	.66-1.36	5-10
Spray Tower[3/]	75 [4/]	99	1.0-1.3	30
Self-Induced Spray	NR [8/]	99 [3/]	1.4	33
Floating Bed*	78	97	1.7	11
Sieve Plate Tower*	96-97	99	4.5-6.2	7
Venturi Scrubber	96 [4/]	99	9-10	5-10
Secondary (With Primary Collection)				
Spray Screen	42 [4/]	88	NA	NA

Applicable	Estimated Efficiencies [6/]		Operating Conditions	
Primary	Particulate	HF	HP/Mcfm[2/]	Gal/Mcf
High Pressure Spray Screen (3 Stage)	93 [4/]	98	6.1	26
Chamber Scrubber	94	94	1.24	4.5-5.0
Crossflow Packed Bed (5 ft. Bed)	87 [4/]	98	1.5-1.8	10+

1/ Footnotes follow Table 5.2d

* Denotes foreign application

Table 5.2c - EQUIPMENT REMOVAL EFFICIENCIES -

HSS SODERBERG POTLINE EFFLUENTS

In Current Use	Efficiencies Derived from Reported Data[1]		Operating Conditions	
Primary	Particulate	HF	HP/Mcfm[2]	Gal/Mcf
Spray Tower	63-80 [4]	91-93	0.3-0.5	1.6-5.0
Floating Bed*	78 [3][4]	98	1.9-2.8	20-40

Applicable	Estimated Efficiencies[6]		Operating Conditions	
Primary	Particulate	HF	HP/Mcfm[2]	Gal/Mcf
Wet Electrostatic Precipitator	98	-	1.4	5-10
Crossflow Packed Bed (5 ft. Bed)	81 [4]	98	1.5-1.8	10+
Self-Induced Spray	62	96	3-6	6-10
Spray Screen	75	93	0.3-0.5	1.6-5.0
Chamber Scrubber	94	94	1.2	4.5-5.0
Secondary (With Primary Collection)				
Spray Screen	25 [4]	80	0.2	10

[1] Footnotes follow Table 5.2d

* Denotes foreign application

Table 5.2d - EQUIPMENT REMOVAL EFFICIENCIES -

BAKE FURNACE

In Current Use	Reported and Vendor Estimated Efficiencies		Operating Conditions	
	Particulate	HF	HP/Mcfm[2]	Gal/Mcf
Dry Electrostatic Precipitator	90 [5]	-	NR	NR
Spray Tower	NA [9]	96	NA	NA
Self-Induced Spray [10]	98 [5]	96 [5]	3.6	6-10

Applicable	Estimated Efficiencies[6]		Operating Conditions	
	Particulate	HF	HP/Mcfm[2]	Gal/Mfc
Incinerators	90 [10]	-	-	-
Wet Electrostatic Precipitator	99 [11]	-	3.8	0.3-0.4

[1] Refer to notes on following page.

Notes - Tables 5.2a through 5.2d

1/ Calculated from industry supplied data.

2/ Horsepower, assuming 50 percent fan and pump efficiency, excluding collection system losses. Precipitator corona power converted to horsepower.

3/ Efficiencies derived from reported information.

4/ Fluoride particulate.

5/ Efficiencies reported by equipment manufacturer.

6/ The estimated particulate efficiencies are obtained from manufacturers, from reports in the literature or from calculations based on dust size distribution and fractional efficiency. The fluoride gas efficiencies and operating conditions are based on equipment manufacturers' information or literature citations.

7/ Estimated efficiencies for equipment not reported but [illegible] use.

8/ Not Reportable (NR) to preserve confidentiality.

9/ Not Available (NA).

10/ Maximum efficiency for hydrocarbon combustion, manufacturers' estimate.

11/ Design basis for precipitators being tested applied to the effluent gas stream after 20 to 30 percent of the particulate has been removed from the cooled effluent gas by a wet device, as per private communication with equipment manufacturer.

shape and location of the air inlet openings and by the draft through the burner. The neck between the skirt and burner must be designed wide enough to prevent blockages which would otherwise occur when the bath splashes. 5.4/

The composition of VSS gas collected and fed to the burners is reported to include about 3 volume percent of hydrocarbons, primarily methane, ethane, propane, butane and their concomitant isomers. After combustion, less than 0.1 volume percent hydrocarbons remain, indicating a combustion efficiency of 96.7 percent (assuming little change in the molar gas throughput). 5.5/

Burners are not applicable to HSS Soderberg cells because the cell construction does not permit skirt collection of relatively undiluted cell effluents, and the resulting hydrocarbon concentration in the effluent gases is too low to support combustion.

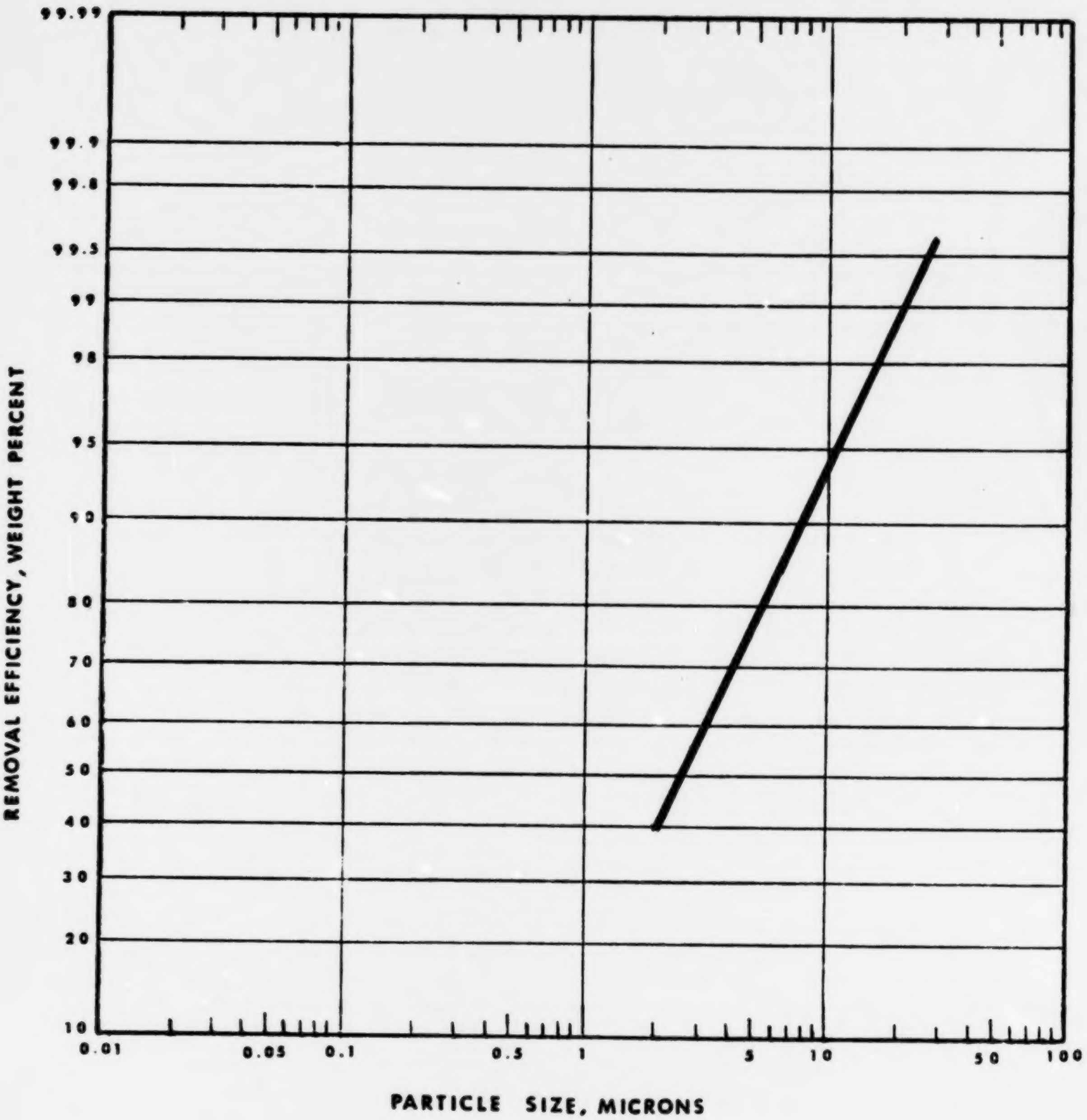
b) Cyclone Collector

The most widely used type of dust collection equipment is the dry cyclone, in which the dust-laden gas enters a cylindrical vessel tangentially, creating inner and outer vortices. The entering gas initially traces the outer vortex down carrying the particulate matter along, then the gas stream reverses direction and traces the inner vortex, heading up towards a centrally located outlet. The dust, because of its inertial characteristics, tends to follow the outside wall down without reversing direction, exiting through a gravity discharge hopper at the bottom. Generally, cyclones are effective for the removal of solids larger than 5 microns diameter as indicated by a typical fractional efficiency curve for a multiple small diameter tube cyclone, Figure 5.3.

The trend in modern installations is to employ multiple tube cyclones for a preliminary particulate removal stage, taking advantage of the economic return to the potline of alumina and particulate fluoride.

Performance data for centrifugal collectors, reported in the literature and by industry questionnaire responses, are summarized in Table 5.3 for prebaked anode and for VSS Soderberg potline applications. From these data average removal efficiencies of 80 and 50 percent

FIGURE 5.3
FRACTIONAL REMOVAL EFFICIENCY
MULTIPLE TUBE CYCLONE



Source: Ref. 5.6/

Table 5.3 - PARTICULATE REMOVAL EFFICIENCIES OF CYCLONE SEPARATORS

Effluent Source	Equipment Designator	Efficiency %	Pressure Drop in.Water	Source
Prebake	MC	85	2.5-3	IQ
	MC	81.4	5.1	IQ
	MC	80.5	3.6	IQ
	MC	77.9	3.5	IQ
VSS Soderberg	MC	40-50	5	IQ
	C	50	N.A.	5.7/
	C	40	N.A.	5.4/
	C	25	N.A.	5.8/

Equipment Designator Code

MC - Multiple Tube Cyclone
C - Cyclone

Source Code

IQ - Industry Questionnaire

have been used in model analyses for prebake and VSS Soderberg potline applications. The multiple tube cyclone is limited to prebake and VSS Soderberg installations where tar fog in the gas stream treated is either absent (prebake) or at a high enough temperature that it does not condense and agglomerate in the equipment, with resultant plugging.

c) Baghouse Filter

One of the most effective methods for removal of dry particulate matter from effluent gas streams is by fabric filtration, in which interstices of the built-up layers become submicron in size. Collection efficiencies of nearly 100 percent can be expected on particulates with a median size of 0.5 micron over the size distribution range of the pollutant dust. 5.9/

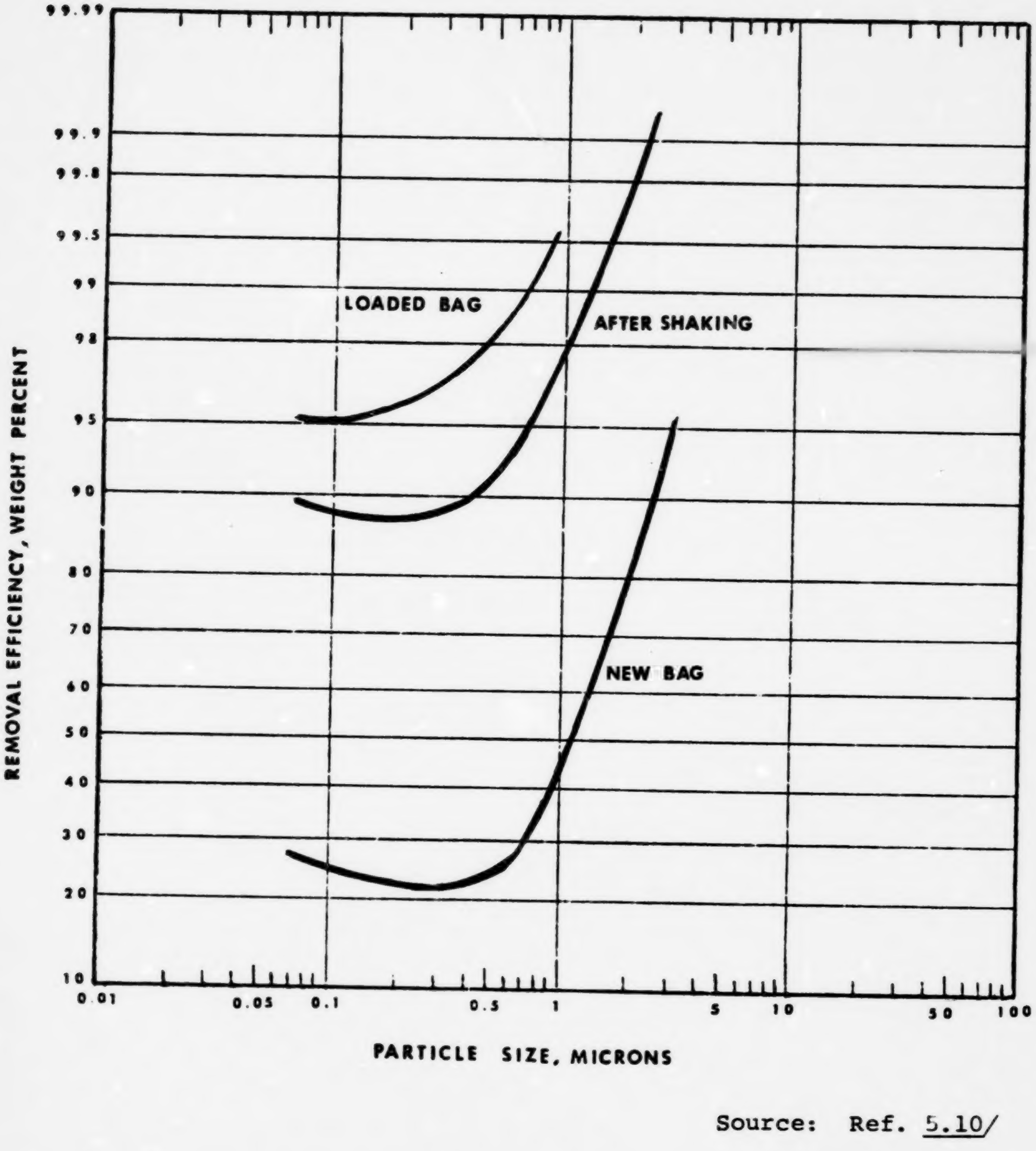
Fabrics are woven or felted, with finer fibers being more effective because they provide more surface area per unit gas volume, resulting in better capture by inertial impaction and interception. The initially clean surfaces pass the gas and some of the particles finer than the space between the fibers, but rapidly accumulate a layer of the entrapped larger particle with resultant reduction in the dimension of the gas flow passages, entrapping finer and finer particulates. In this manner particulate removal efficiencies approaching 100 percent are rapidly achieved, unequalled at comparable power requirements by other means of separation. 5.9/ Typical fractional efficiency curves are shown in Figure 5.4.

The filter cake is removed intermittently by reversal of the gas flow and/or shaking the filter cloth. Bag filters are suitable for dry materials handling operations and all of the carbon plant operations, (except pitch fume abatement and anode baking), since these effluent gases are free from condensible constituents which might blind the filters. Bag filters are not used on potline effluents except as part of a dry scrubbing system.

FIGURE 5.4

FRACTIONAL REMOVAL EFFICIENCY

BAGHOUSE FILTERS



Source: Ref. 5.10/

d) Dry Scrubbing Systems

By combining the mechanisms of HF adsorption on alumina and mechanical separation of particulates, removal of both particulates and gaseous fluorides can be accomplished in a single system. A major advantage is the return of the recovered fluoride materials to the potlines without need for further processing to make them available to the reduction process.

The dry scrubbing of HF by alumina is made possible because the adsorbed HF appears to form a chemical bond with the alumina, as evidenced by the fact that the HF is not driven off when the reacted alumina is heated on feeding to cell bath. The adsorbed or "chemisorbed" HF reacts with alumina to form aluminum fluoride and water.

Three processes involving the dry scrubbing principle have been developed and put into practice. Table 5.4 summarizes removal efficiencies for these systems as developed from user information.

Variations among the systems lie in the character of the alumina used as HF adsorbent, the methods of obtaining gas contact with the adsorbent, and the designs of the mechanical separation devices to remove the particulates, including the absorbent, from the gas stream.

Coated Filter Dry Scrubber Systems, the Alcoa 173 (reference 5.11/) and the Wheelabrator (reference 5.12/), are similar in that finely ground reactive alumina is injected into the effluent gas stream to form a layer on fabric filter bags. Effluent particulates are captured on this layer and HF is adsorbed on the alumina when passing through it. The amount of injected alumina used is noted in the Alcoa patent as being between 3 and 20 percent by weight of the total alumina feed to the reduction cell, an amount far in excess of that theoretically required to convert the gaseous fluorides to aluminum fluoride. Catch from the baghouse is blended with additional cell grade alumina and fed to the pots. Figure 5.5 shows a process flow diagram.

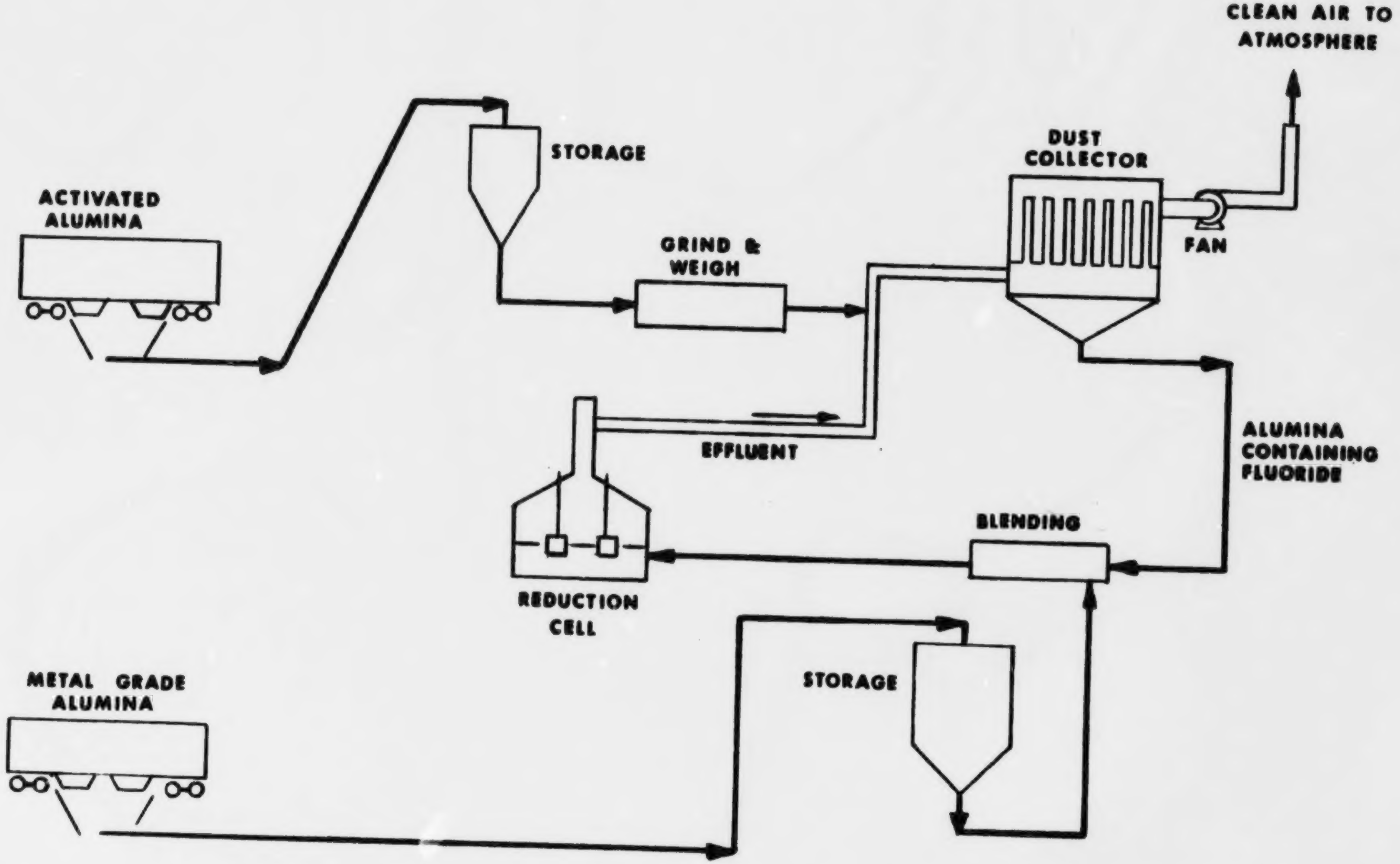
This type of system has been used on prebake potlines but is being replaced by other dry scrubbing systems in several installations.

Table 5.4 - REMOVAL EFFICIENCIES OF DRY SCRUBBING SYSTEMS

System/Application	Equipment Designator	Fluoride Removal Efficiencies, %		
		HF	Particulate	Total F
Coated Filter Dry Scrubber/PB	CFDS	90	98	93.4
Fluid Bed Dry Scrubber/PB	FBDS	99	98	98.6
Fluid Bed Dry Scrubber/VSS*	FBDS	99	98	98.9
Injected Alumina Dry Scrubber/PB*	IADS	98	98	98
Injected Alumina Dry Scrubber/VSS*	IADS	98	98	98

* Denotes Foreign Application

FIGURE 5.5
COATED FILTER DRY SCRUBBER
PROCESS FLOW DIAGRAM


CLEAN AIR TO ATMOSPHERE
STORAGE
DUST COLLECTOR
ACTIVATED ALUMINA
GRIND & WEIGH
FAN
EFFLUENT
ALUMINA CONTAINING FLUORIDE
BLENDING
REDUCTION CELL
STORAGE
METAL GRADE ALUMINA

The Fluid Bed Dry Scrubber (Alcoa System 398) employs a fluidized bed of sandy alumina to contact and adsorb HF and to trap particulates. Ore grade alumina is continuously fed to the reactor bed in amounts up to 100 percent of the potline feed requirements and the reacted bed material overflows and is used as cell feed. Virtually all of the effluent particulate is trapped in the fluid bed, (perhaps by electrostatic agglomeration). Fugitive particulate, primarily alumina, is stopped by a bag filter mounted over the reactor. The bags are cleaned intermittently, dropping the catch back into the fluid reactor bed. Figure 5.6 illustrates this process. 5.13/ 5.14/ 5.15/ 5.16/

Alcoa reports that, with proper operating and maintenance procedures, this system is capable of 98 percent particulate and 99 percent HF removal efficiencies on prebake potline effluents.

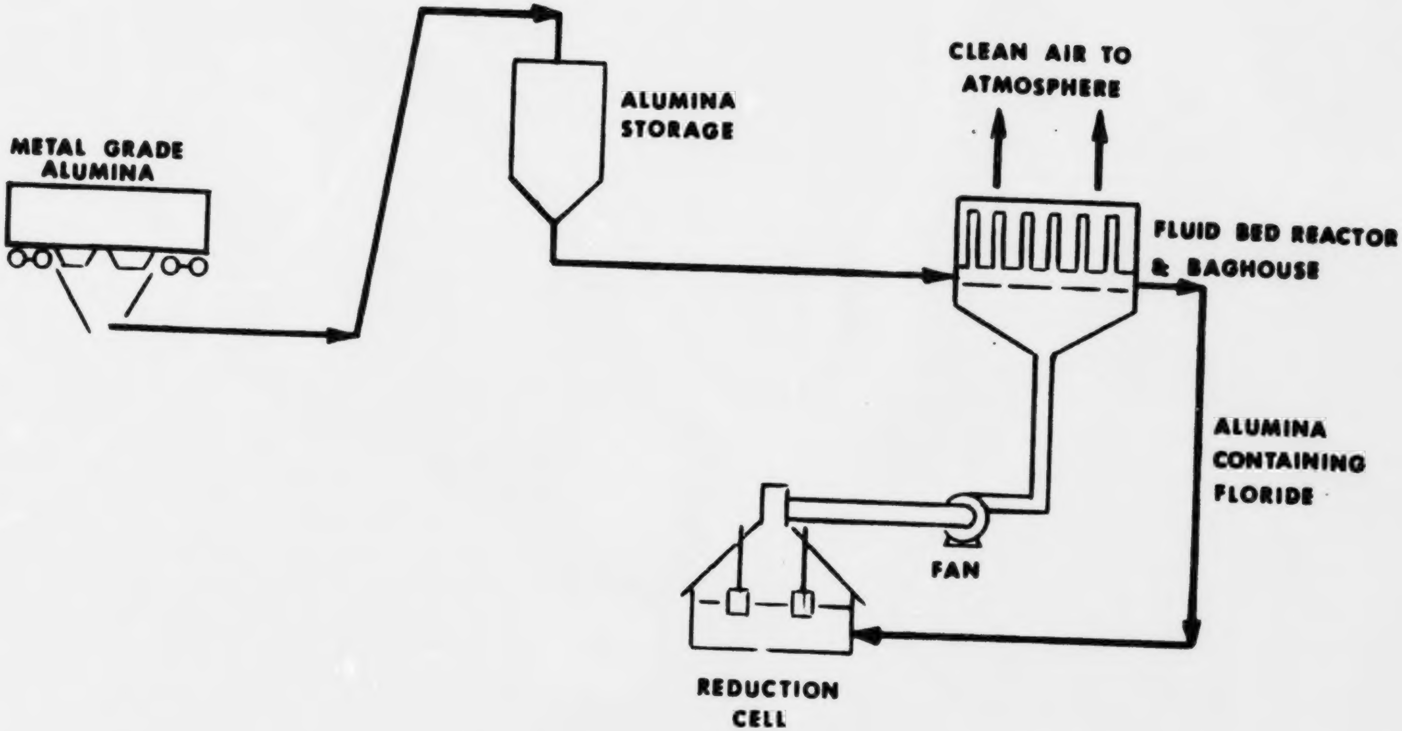
The fluid bed dry scrubber has been applied in foreign plants to VSS Soderberg effluents with pilot lights or other devices being used to ensure all burners being lit. The system has not been applied to HSS Soderberg effluents and has not been used in domestic VSS service.

The Injected Alumina Dry Scrubber was developed by Aluminum Company of Canada for the removal of particulates and gaseous fluoride from the effluent streams of prebake and VSS Soderberg anode potlines. The process depends on the chemisorption of HF on ore grade alumina followed by fabric filtration to capture all particulates including the adsorbed HF.

The claimed removal efficiencies compare with those of the fluid bed dry scrubber but the method of achieving contact between the effluent gas stream and the alumina adsorbent differs.

For prebake potline applications, ore grade alumina is injected into the effluent stream. After sufficient time to achieve gas-solid contact, this dust cloud is intercepted by bag filters operating at an air-to-cloth ratio of about 6 cubic feet of air per minute per square foot of filter area and a pressure drop of approximately 6 inches water gage. Collected alumina,

FIGURE 5.6
FLUID BED DRY SCRUBBER
PROCESS FLOW DIAGRAM


METAL GRADE ALUMINA
ALUMINA STORAGE
CLEAN AIR TO ATMOSPHERE
FLUID BED REACTOR & BAGHOUSE
ALUMINA CONTAINING FLORIDE
FAN
REDUCTION CELL

its adsorbed HF, and potline solid effluents are fed to the cells without further treatment.

Effluent streams from VSS Soderberg potlines have higher concentrations of HF than prebake effluents and they may contain unburned tar fumes. Here again, ore grade alumina is injected into the effluent stream, but from this point on, the Alcan process is modified slightly. An arrangement is made to separate the bulk of the alumina containing adsorbed HF from the portion containing unburned hydrocarbons. The latter minor quantity of alumina is calcined to remove the tar prior to being returned to the cells along with the main portion of the collected alumina. This system does not require that all burners be lit all the time.

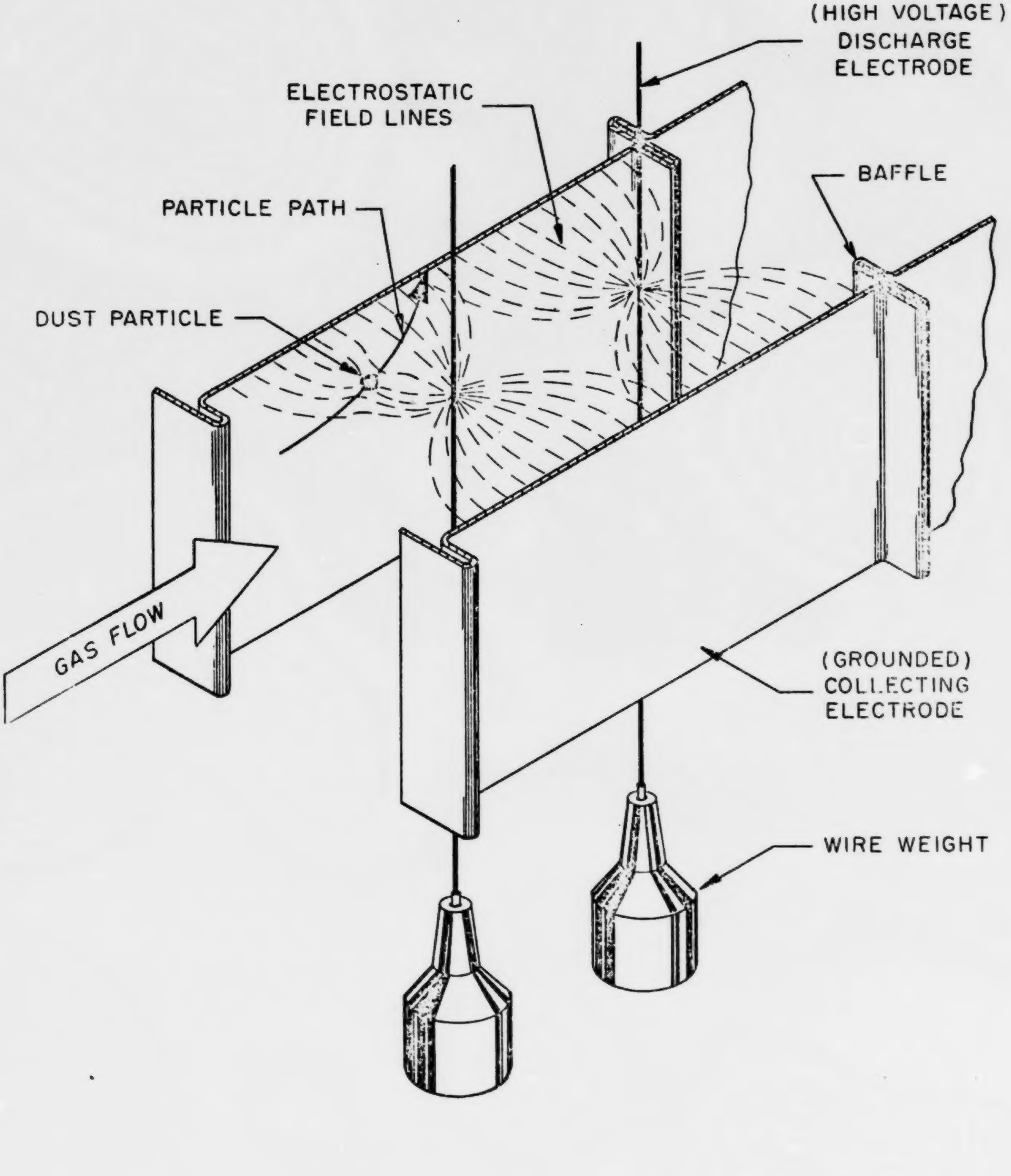
Removal efficiencies of 98 to 99 percent on dust and HF have been reported for a full prebake potline application. The vendor expects to achieve 97 to 98 percent on dust and HF on a full line VSS Soderberg installation.

e) Electrostatic Precipitator

The electrostatic precipitator is contained in a relatively large chamber through which effluent gas streams pass at low velocity, usually 3 to 5 feet per second. In its usual form, high negative voltage corona discharge wires are suspended across the air stream and grounded collector plates form parallel passageways for the air. The ionizing field surrounding the discharge wires ionizes part of the gas stream and imparts electric charge to most particles, some positive but most negative. Positively charged particles migrate toward the discharge wires and negatively charged particles migrate to the grounded collection plates. When collected particles lose their charges, they tend to agglomerate and collect on the surfaces. Figure 5.7 illustrates the particle charging collecting mechanism. Figure 5.8 shows the arrangement of a dry electrostatic precipitator with mechanical rappers to dislodge particles from the discharge wires and collector plates.

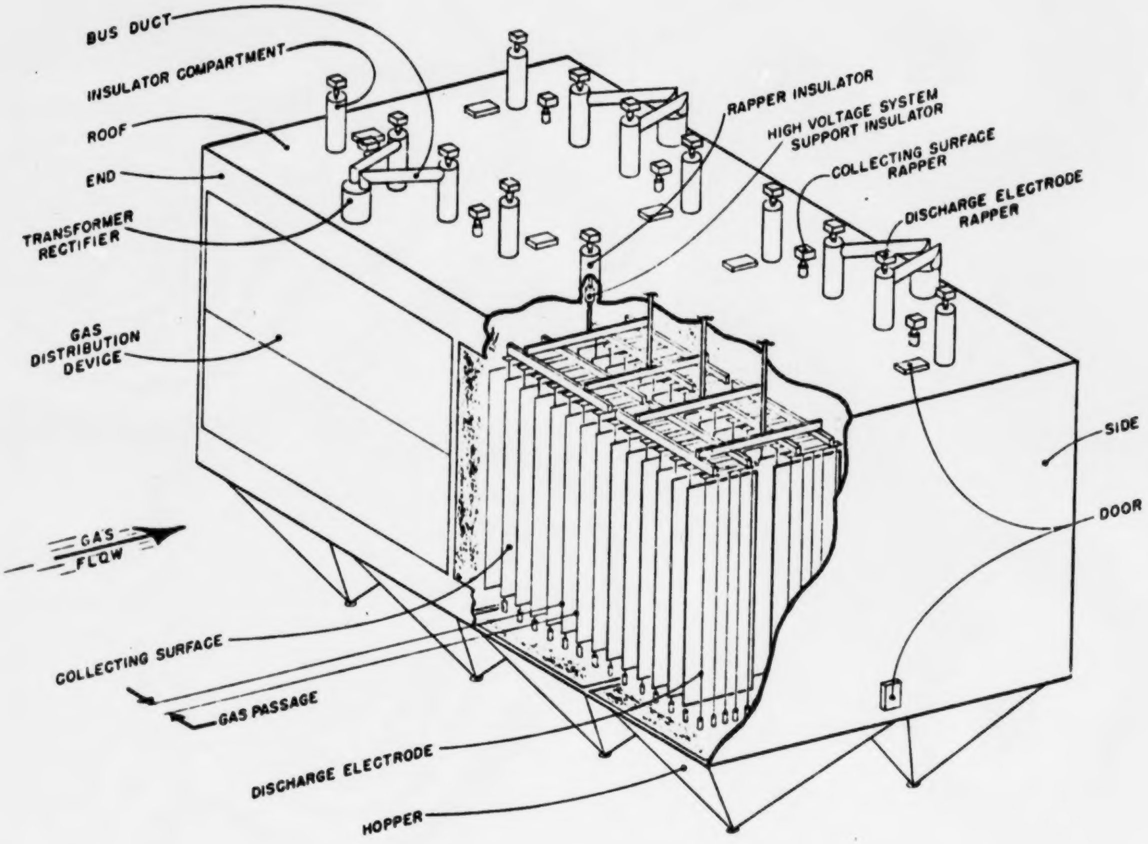
The removal efficiency of electrostatic precipitators for many kinds of particulate is improved if the entering gas is conditioned by raising its moisture content. Two tests on similarly designed dry electro-

FIGURE 5.7
ELECTRONIC CHARGING OF DUST PARTICLES


(HIGH VOLTAGE)
DISCHARGE
ELECTRODE
ELECTROSTATIC
FIELD LINES
BAFFLE
PARTICLE PATH
DUST PARTICLE
GAS FLOW
(GROUNDED)
COLLECTING
ELECTRODE
WIRE WEIGHT

COURTESY UNIVERSAL OIL PRODUCTS

FIGURE 5.8
DRY ELECTROSTATIC PRECIPITATOR ARRANGEMENT


BUS DUCT
INSULATOR COMPARTMENT
ROOF
END
TRANSFORMER RECTIFIER
GAS DISTRIBUTION DEVICE
GAS FLOW
COLLECTING SURFACE
GAS PASSAGE
DISCHARGE ELECTRODE
HOPPER
RAPPER INSULATOR
HIGH VOLTAGE SYSTEM SUPPORT INSULATOR
COLLECTING SURFACE RAPPER
DISCHARGE ELECTRODE RAPPER
SIDE
DOOR

COURTESY INDUSTRIAL GAS CLEANING INSTITUTE static precipitators operating on prebake potline effluents showed 98 percent removal efficiency with 2.4 mol percent moisture and 91.5 percent removal with 0.7 mol percent moisture. 5.17/ Sprays or other devices upstream of an electrostatic precipitator may be required to realize its full removal potential. When applied to VSS or HSS Soderberg potlines, precipitators are usually preceded by a wet scrubbing device which both conditions the gas and removes most HF.

Electrostatic precipitators fall into two categories, dry or wet, depending on whether the collected particulates are knocked off the plates and wires by mechanical rapping to be gathered dry in a hopper, or whether the plates and wires are washed with falling water or electrostatically collected mist and the particulates removed as a slurry.

Dry electrostatic precipitators find useful application in prebake and VSS Soderberg primary potline effluent cleaning, and in the collecting of dry particulates from materials handling, grinding, and grit blasting operations such as occur in carbon plants. Wet electrostatics are applied effectively to VSS and are being tested on a prototype basis on HSS Soderberg primary potline effluents.

Electrostatic precipitators, both wet and dry, operating on potline primary effluent streams report design and operating removal efficiencies ranging from 60 percent to 99 percent on particulate. Unlike many types of control equipment, electrostatic precipitators may be designed for almost any selected efficiency. By using conservative design dimensions, by controlling humidity of the incoming gas, and by operating at high voltage, both wet and dry precipitators can achieve 98 to 99 percent removal of potline effluent particulates.

Table 5.5 summarizes available data on performance of systems incorporating electrostatic precipitators in potline applications and shows the values selected for use in the model systems analysis in Section 8 of this report.

Table 5.5 - ELECTROSTATIC PRECIPITATOR PERFORMANCE DATA AND MODEL SUMMARY

System Number	Anode Type	Equipment Designator	Removal Efficiencies, % Fluoride			Data Source
			Gaseous	Particulate	Total	
1	PB	DESP	-	98	-	5.17/
2	PB	DESP	-	91.5	-	5.17/
3	PB	DESP & WS	-	-	94-96	I.Q.
4	PB	MC & WESP & WS	-	-	87-93	I.Q.
5	VSS	MC & DESP	-	90-98	-	5.5 5.8 5.18 5.19/
6	VSS	WS & WESP	99.9	98.9	99.6	5.20/
7	VSS	WS & WESP	-	-	98.89	I.Q.
8	HSS	WS & WESP	-	98	-	P.C.
Model	PB	DESP		98		System No. 1
Model	VSS	DESP		98		System No. 5
Model	HSS	WESP		98		System No. 8
Model	VSS	WESP		99		System No. 6

Equipment Designator Code

DESP - Dry Electrostatic Precipitator
WS - Wet Scrubber
MC - Multiple Tube Cyclone
WESP - Wet Electrostatic Precipitator

Source Code

I.Q. - Industry Questionnaire
P.C. - Private Communication From Equipment Manufacturer

f) Spray Tower

The spray tower is the most common type of removal equipment used in aluminum potline effluent service. Properly operated and maintained these devices can achieve removal efficiencies for potline HF ranging from the low to high nineties. Particulate removal efficiencies for spray towers alone are much lower, but in combination with multiple cyclones in prebake and VSS Soderberg service overall particulate efficiencies in the eighties are achieved.

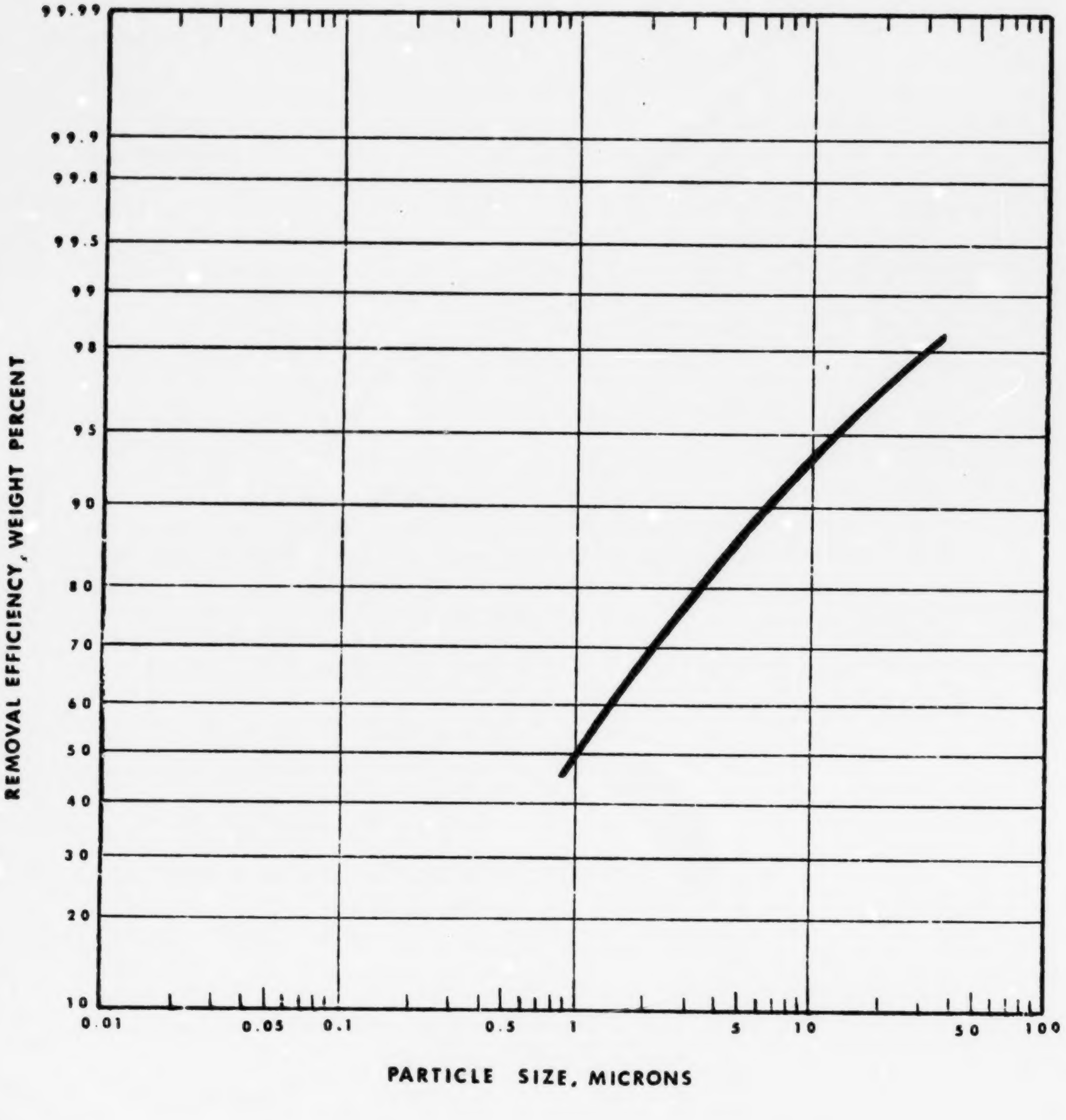
The term spray tower is applied to gas scrubbing devices in which the gas passes through an enclosure at relatively low velocity and is contacted by water, alkaline liquor or limed water liquor, sprayed from headers usually in counterflow with the gas. In prebake or HSS potline service the units may range from 38,000 to 630,000 ACFM capacity and may spray from 1.7 to 10 gallons of liquor per thousand cubic feet of gas. A typical spray tower in prebake service uses water or limed water and consists of an open top redwood tower, 12 to 15 feet diameter and 40 to 70 feet high, with cyclonic inlet breeching and a mist eliminator at the top. Liquor may be sprayed down from the top or at several elevations in the tower.

Compared with other types of wet scrubbing equipment, spray towers show relatively low removal efficiency for fine particulates. Figure 5.9 shows removal efficiency versus particle size for a gravity spray tower spraying at a rate of 18 gallons of water per thousand cubic feet of air. The spray tower for which fractional efficiency curves are shown in Figure 5.10 uses only 5 gallons per thousand cubic feet in high pressure sprays and achieves much higher particulate removal efficiency.

HSS Soderberg effluent gases contain unburned hydrocarbons to the extent that dry collectors upstream of a scrubber cannot be used because they would become fouled by condensed tars. Spray towers in HSS Soderberg service appear to perform less efficiently than similar scrubbers in prebake or VSS Soderberg service. This has been suggested to be the result of an interference by the hydrocarbons in the wetting of the particulates and diffusion of HF to the spray droplets.

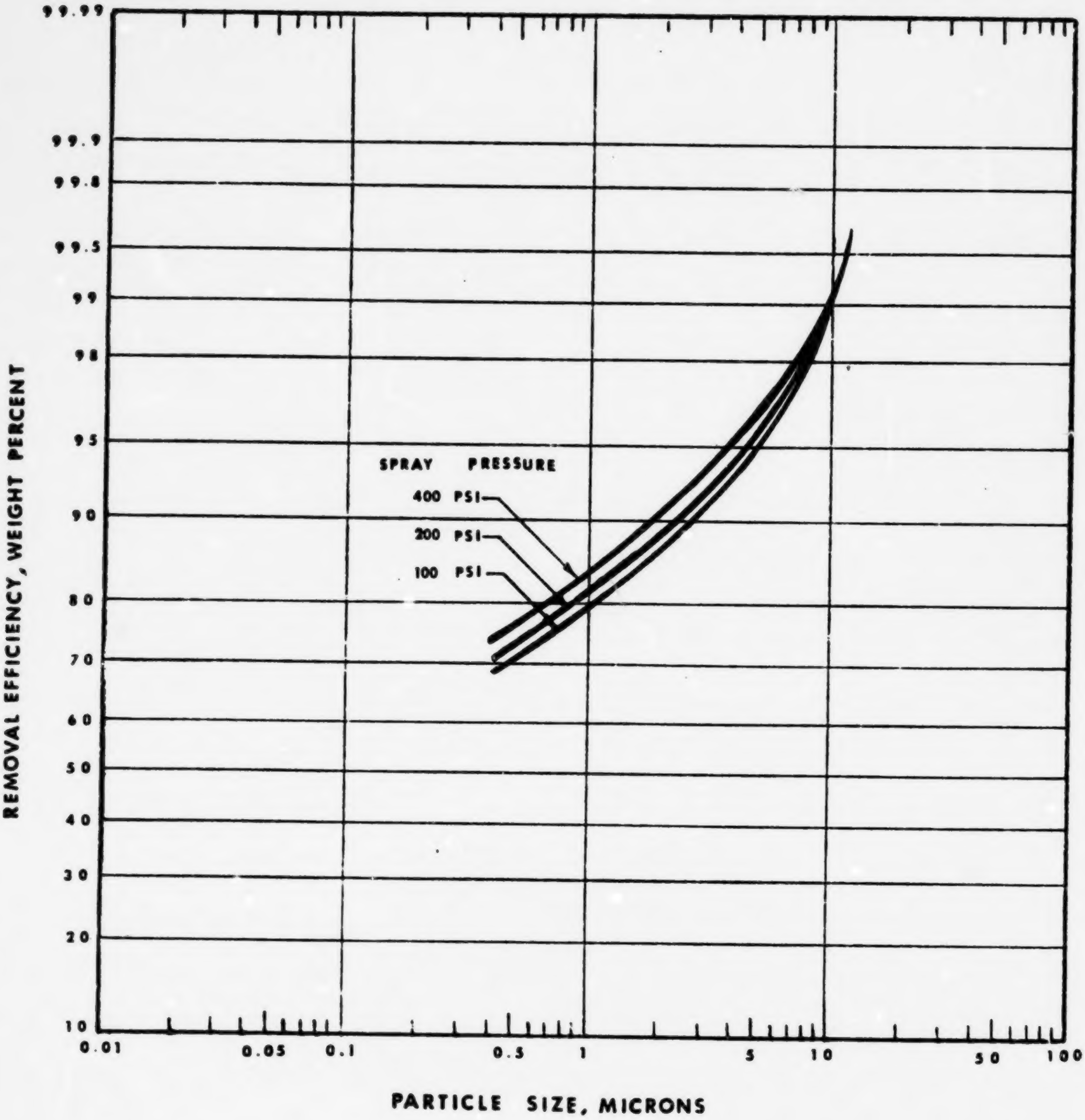
FIGURE 5.9

FRACTIONAL REMOVAL EFFICIENCY GRAVITY SPRAY TOWER



Source: Ref. 5.21/

FIGURE 5.10
FRACTIONAL REMOVAL EFFICIENCY
HIGH PRESSURE SPRAY TOWERS



Source: Ref. 5.22/

Table 5.6 presents operating characteristics and removal efficiencies for several aluminum potline effluent control systems which include spray towers. Removal efficiency data for spray scrubbers alone are sparse. The interpretation of industry response is complicated by the fact that various efficiencies were reported for systems using various types of scrubbing liquors, various inlet scrubbing liquor concentrations and various bases (overall fluoride, gaseous fluoride and total particulate, and gaseous fluoride and particulate fluoride).

The scrubber liquor chosen for the model is a limed water with an inlet concentration of 200 parts per million fluoride. Model efficiencies correspond to this type liquor at this concentration; any higher inlet liquor concentrations with the same inlet gas concentration can be expected to yield lower gas efficiencies. This liquor circuit includes a treatment facility which precipitates the fluoride as calcium fluoride and returns the overflow liquor at 200 ppm fluoride to the scrubber.

HF Removal Efficiencies

The removal of HF in the systems reported in Table 5.6 results from the scrubbing action of the spray towers, as the other components are dry removal equipment preceding the scrubber in the system of a wet electrostatic precipitator following.

From the internal evidence contained in the industry reports, the HF removal efficiencies which can be achieved for prebake and VSS Soderberg service spray tower scrubbing with lime treated water recycle circuits assumed for the model are 95 and 99 percent respectively. The best HF removal efficiency reported for a composite of several spray towers in HSS Soderberg service was 93 percent. These removal efficiencies were adopted for use in the model analyses of Section 8.

Particulate Removal Efficiencies

Spray tower removal efficiencies for particulate fluorides are directly derivable from only very limited reported data and usually have little utility because most control systems include some device in addition to a spray tower for particulate removal. However

Table 5.6 - REMOVAL EFFICIENCIES OF SPRAY TOWER SYSTEMS

No.	Anode Type	Equipment Designator	Air Pres. Drop In. Water	Liquor Gal/Mcf	Removal Efficiency, %		
					HF	Particulate	Total F
1	PB	MC & ST	-	6.7	-	-	88.5
2	PB	MC & ST	0.5	10.0[1]	88.9	94.8	-
3	PB	MC & ST	1.8	3.5	-	87.5	79.2
4	PB	ST	3.0	1.7	-	-	73
5	PB	DESP & ST	3.0	5.3-8.0[2]	98.4	89-90	94-96
6	PB	DESP & ST	3.0	5.3-8.0[3]	95*	95	94-96
7	PB	DMS & ST	8.0 (Total)	6.7-9.3[2]	98.4	-	78-86
8	PB	MC & DESP & ST	4.0 (Total)	3.5[3]	89.8	-	87-93
9	VSS	B & ST	2.5	9.4[3]	-	-	90-95
10	VSS	B & ST & WESP	8.0 (Total)	30	-	-	98-99
11	HSS	ST	-	1.6-5.0[4]	93[4]	63.5[4]	81.4[4]
12	HSS	ST	-	3.9	90.7	79.6	87.0

Notes

1. Scrubber liquor contained 2000 to 4000 ppm dissolved fluoride for cryolite recovery. When operated with limed liquor, reported efficiency was 93 to 95 percent.
2. Once through water circuit.
3. Recycled limed liquor circuit.
4. Composite of multiplant results.

* Derived from reported data.

Legend

MC - Multiple Cyclone
ST - Spray Tower
DESP - Dry Electrostatic Precipitator
DMS - Dynamic Mechanical Separator
B - Burner
WESP - Wet Electrostatic Precipitator

for the sake of model analysis the following solid F removal efficiencies have been derived for spray towers alone. Where a spray tower follows a solids collector, the particulate removal of the spray tower has been ignored.

Prebake

Comparison of the fractional efficiency curves for spray towers and multiple tube cyclones indicate that both types of equipment should show approximately equal overall removal efficiencies for prebake particulate effluent. Therefore, the value 80 percent was taken, equal to multiple tube cyclone particulate fluoride removal efficiency for prebake.

VSS Soderberg

Assuming that VSS Soderberg particle size distribution is somewhat finer than prebake, the assumed removal efficiency for spray towers on VSS solid fluoride particulate is taken as 75 percent.

HSS Soderberg

A composite report of multiplant experience on HSS Soderberg solid fluoride particulate removal in spray towers shows 64 percent removal efficiency. This is used in the model analysis of Section 8.

Table 5.7 summarizes the model efficiencies used in Section 8 for spray towers.

g) Spray Screen

The term spray screen scrubber is applied to wet scrubbing equipment in which the liquor is sprayed into an effluent gas stream and on to screens or open mesh filters enclosed in a plenum chamber. The assembly also usually includes a mist eliminator. Effluent gas flow may be powered by exhaust fans, or may be moved by unpowered convection.

The removal mechanisms, as in other wet scrubbers, are inertial impaction on, interception by, and adsorption into, the liquid droplets or filters.

Table 5.7 - SUMMARY OF MODEL REMOVAL EFFICIENCIES FOR SPRAY TOWERS

ESTIMATED FROM INDUSTRY QUESTIONNAIRE DATA

Application, Cell Type	Model Efficiencies, % Fluoride		
	Gaseous	Particulate	Total
Prebake	95	80	88.7
VSS Soderberg	99	75	93.0
HSS Soderberg	93	64	82.0

The low gas pressure drop across spray screen scrubbers and the relatively low power cost recommends them for secondary, or potroom scrubbing service. Figures 5.11 through 5.14 illustrate several designs of spray screen scrubber installations which have been used in the primary aluminum industry.

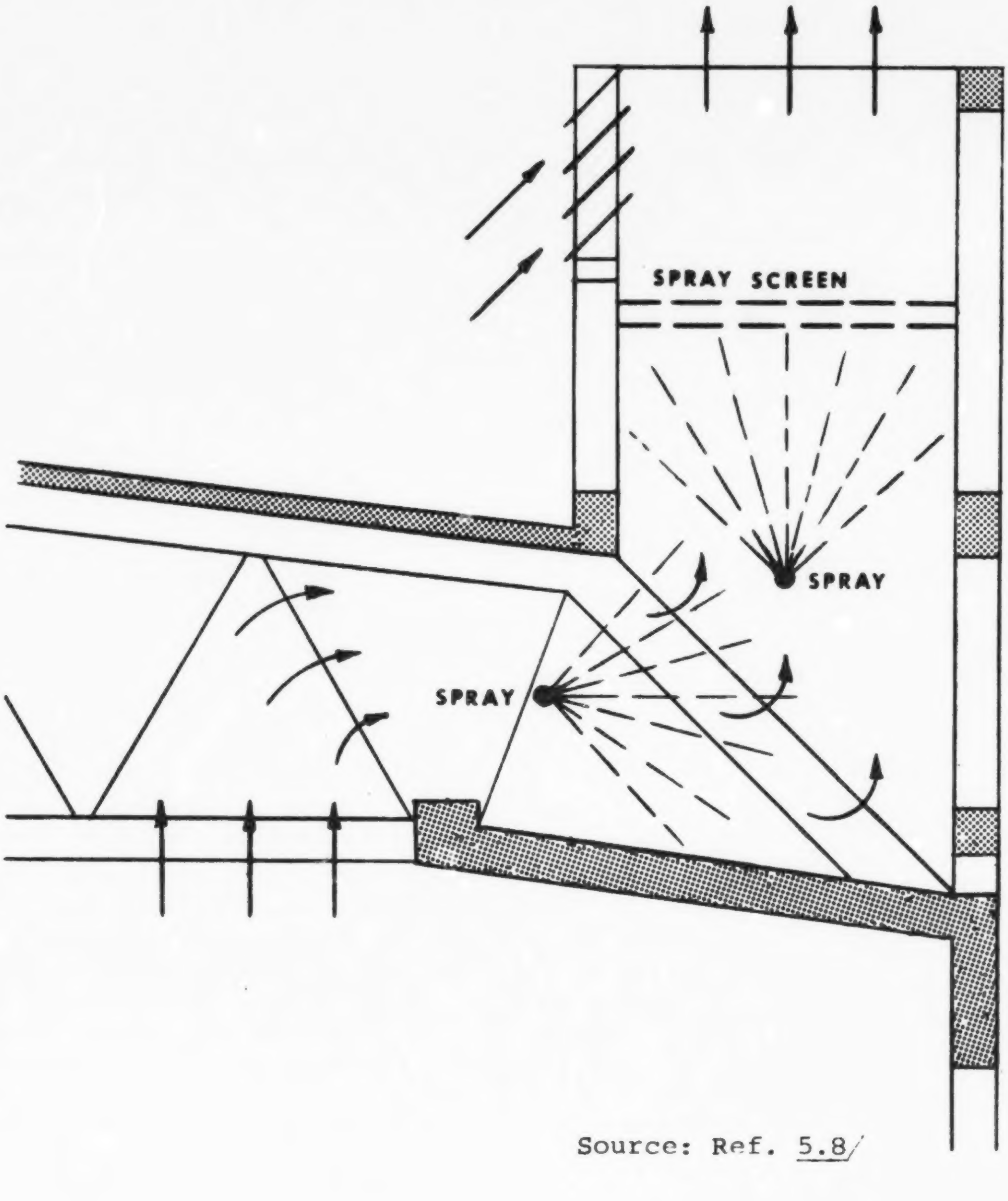
Performance data on spray screen installations are scant and are difficult to establish with accuracy because of the large volumes and low concentrations handled in the systems to which they are applied. One foreign prebake plant reports 90 percent total F removal, 5.26/, and another reports greater than 90 percent for HF and approximately 50 percent for particulate fluoride in secondary scrubbing without primary control, 5.27/. One VSS Soderberg plant using a spray screen secondary in addition to a primary system reports for the secondary system 88 percent HF, 77 percent total particulate, 42 percent solid F, and 72 percent total F removal efficiencies, 5.20/.

Removal efficiencies used in the model analysis of Section 8 were derived from these data and from limited information in the industry questionnaire responses. Values chosen are:

		Solid F	HF
Secondary System No Primary		45	93
Secondary System With Primary	PB	25	80
	VSS	42	88
	HSS	25	80

While more sophisticated scrubbing devices achieve higher removal efficiencies on both particulates and HF than does the spray screen, the costs are 30-100 percent greater and the cost effectiveness much lower, when applied to secondary treatment. It is the consensus of the industry that, for secondary treatment in combination with primary control, the cost differential would be more effectively invested in improved primary collection and removal equipment. Among the alternative secondary scrubbers only the spray screen is considered economically feasible.

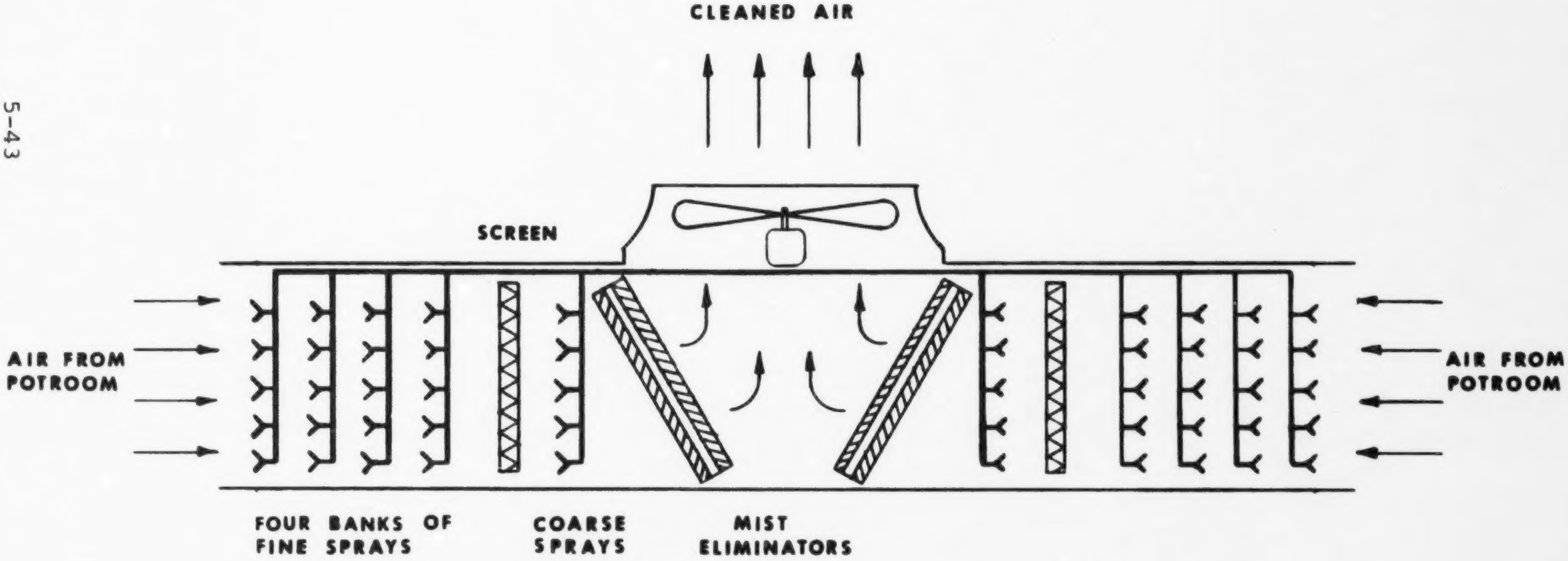
FIGURE 5.11
UNPOWERED ROOF SPRAY SCREEN


SPRAY SCREEN
SPRAY
SPRAY

Source: Ref. 5.8/

FIGURE 5.12

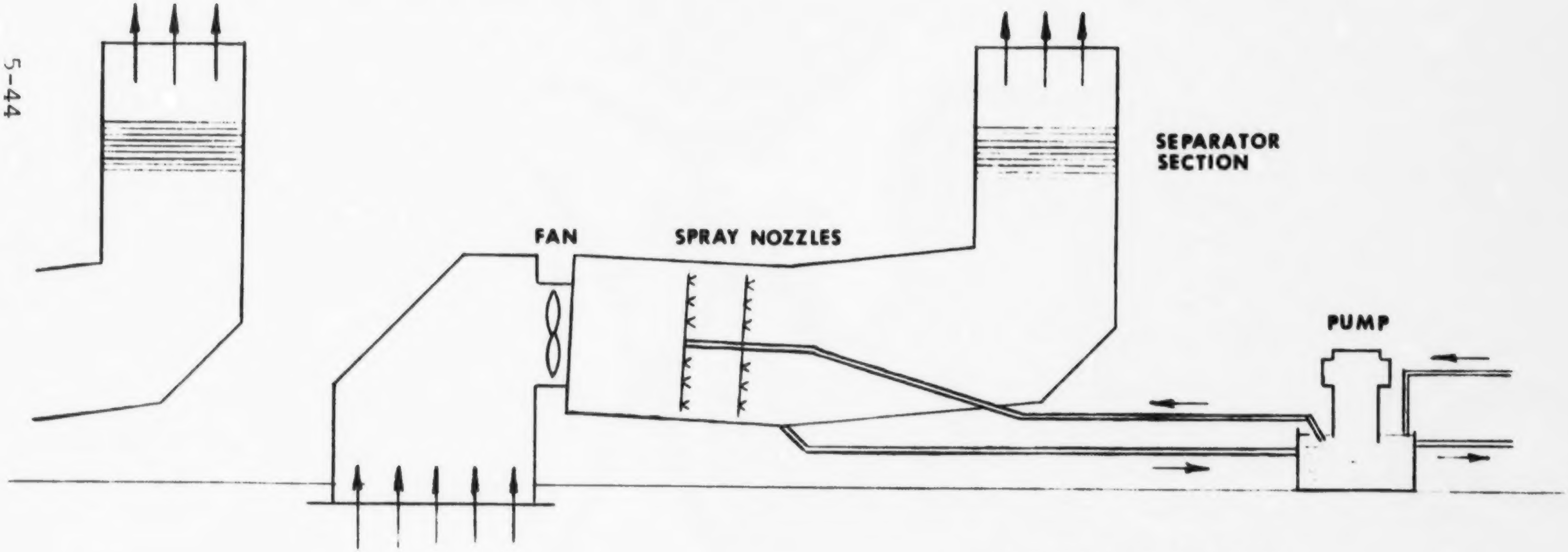
POWERED CELLROOM SPRAY SCREEN SCRUBBER


CLEANED AIR
SCREEN
AIR FROM POTROOM
AIR FROM POTROOM
FOUR BANKS OF FINE SPRAYS
COARSE SPRAYS
MIST ELIMINATORS

Source: Ref. 5.20/

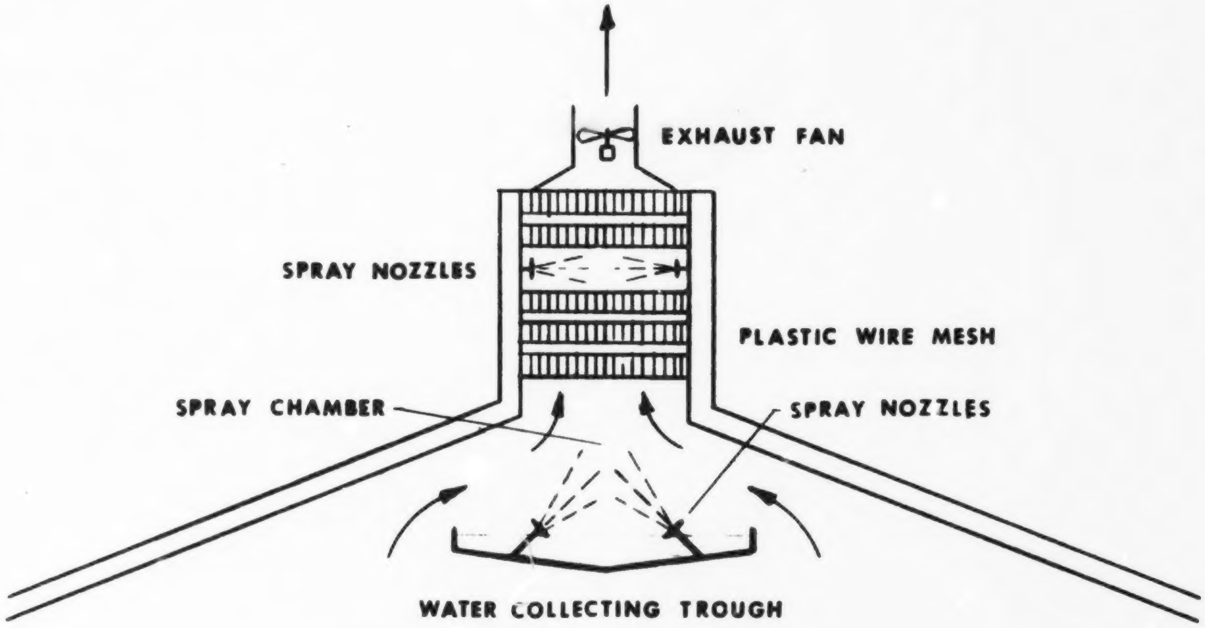
FIGURE 5.13

POWERED SPRAY SCREEN SCRUBBER


FAN
SPRAY NOZZLES
SEPARATOR SECTION
PUMP

Source: Ref. 5.36

FIGURE 5.14
POWERED MONITOR SPRAY SCREEN SCRUBBER


EXHAUST FAN
SPRAY NOZZLES
PLASTIC WIRE MESH
SPRAY CHAMBER
SPRAY NOZZLES
WATER COLLECTING TROUGH

Source: Ref. 5.27/

h) Venturi Scrubber

The venturi type scrubber contains a reduced flow area or throat section in the main air duct in which the velocity is increased many-fold, followed by a diffuser section. Scrubbing liquor introduced at the throat is sheared by the high velocity gas and is dispersed and mixed with the gas as an extremely fine spray. Droplets interact with HF and particulates in cell effluent streams and are removed from the gas stream in some form of entrainment separator. Full advantage of the potential of a venturi as a scrubber is realized if the gas entering the throat is saturated with water vapor. Additional injected water evaporating in the throat will condense out when the static pressure rises in the diffuser section, thus providing additional sites or nuclei for absorbing gas and particulates.

Normally operated at 20 to 40 inches of water pressure drop, the venturi shows removal efficiencies in the high nineties for both HF and most particulates. Incomplete tests with the effluent from HSS Soderberg potlines indicate that the removal efficiencies for hydrocarbon fumes may be lower.

Venturi scrubbers have been applied to the control of VSS Soderberg potline effluents and are currently undergoing tests in bake plant service. Operating costs for high particulate removal are considered by the industry to be unacceptable for prebake service.

Industry questionnaire response for VSS Soderberg services reports for a venturi system (with a packed bed separator section), an overall fluoride removal efficiency of 98 to 99 percent with a gas pressure drop of 30 inches water column and a liquor rate of 5 to 10 gallons per thousand cubic feet. This overall efficiency, based on reported fluoride distribution between gas and particulate and an assumed gas removal efficiency of 99 percent (because of packed separator section), yields a fluoride particulate removal efficiency of 96 percent. These values were adopted for the model analysis in Section 8.

i) Chamber Scrubber

The chamber scrubber consists of spray nozzles and venturi throat pieces, assembled in a staggered arrangement in a horizontal cylindrical steel vessel which may be lined for corrosion protection. The effluent gases are scrubbed by liquid spray action which provides enough suction to partially entrain particulate and gas and carry them into the throat section where thorough mixing occurs. Gases cannot bypass the spray and the accelerated gas velocity provides opportunity for high impact of spray particles. The numbers of passes, venturi throats and nozzles are a function of the volume and characteristics of the gas and the level of removal efficiency desired. The final design is customized to meet service conditions.

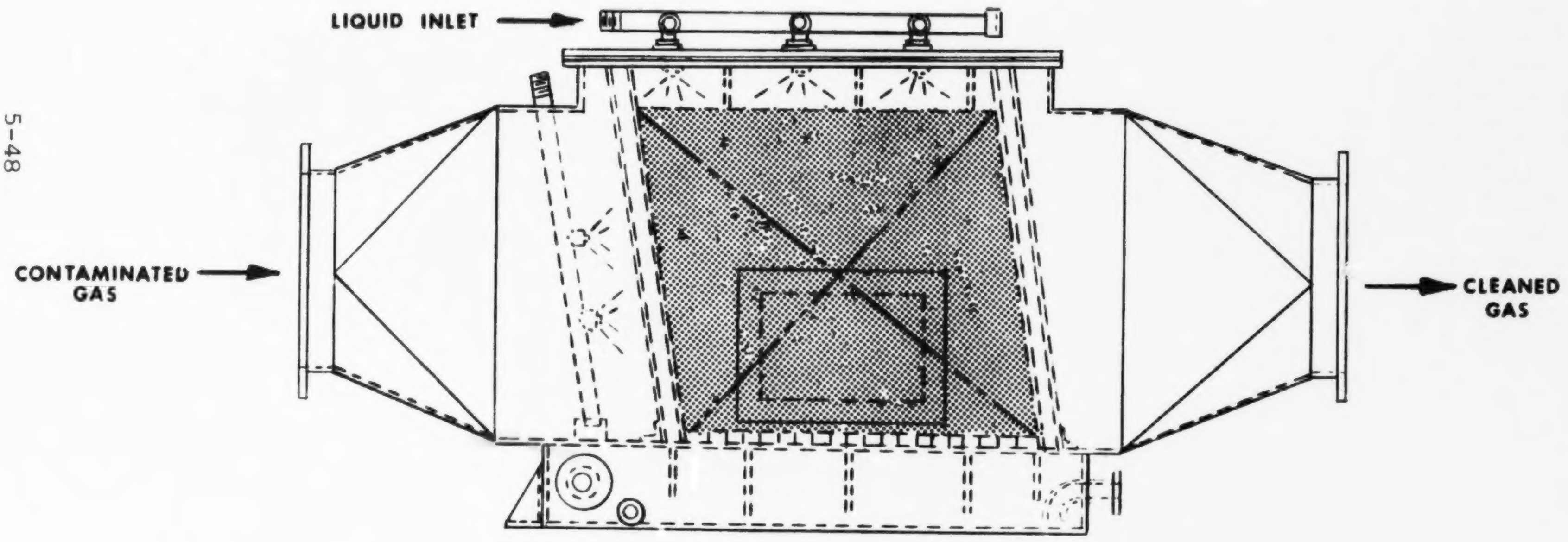
This type of scrubber has been recently installed in a prebake potline primary control system but no operating data are available. Costs for application in secondary treatment are considered by the industry to be unacceptable.

j) Cross Flow Packed Bed Scrubber

Packed bed wet scrubbers remove entrained particulates by inertial impingement against wet surfaces of packing material and remove HF gas by diffusion. The interception mechanism, by which particulates in the one-micron range are most readily collected, plays a minor role in packed bed scrubbers. It has been suggested that similar electrostatic charges on the particulates and packing tend to repel the lighter particulates. 5.23/ For this reason, packed bed scrubbers may show relatively poor efficiency in controlling the approximately half-micron particulates which contribute most to opaque emissions.

The crossflow configuration shown in Figure 5.15 may have advantages over the older vertical packed tower arrangement where the gas flows up countercurrent to scrubbing liquor which drips down through the bed. The crossflow bed has an inherently lower pressure drop than a vertical bed for equal capacity because the liquid and gas streams interact at right angles rather than in direct opposition. Further, this flow geometry is responsible for the non-flooding characteristics of the

FIGURE 5.15
CROSSFLOW PACKED BED SCRUBBER


LIQUID INLET
CONTAMINATED GAS
CLEANED GAS

COURTESY CEILCOTE COMPANY

crossflow bed. The first foot or so of packing may be washed with considerably more liquor than the back part of the bed effecting turbulent washing action to remove most of the particulate and to prevent blinding. In addition, if the gas can be cooled below its dewpoint early in the bed, condensate nuclei formed downstream will provide additional sites for absorbing gas and particulates.

The crossflow packed bed is used in one secondary application on prebake potlines. Based on available information the following values have been selected for model analysis:

Application	Removal Efficiency, Percent Solid F	Removal Efficiency, Percent HF
Primary Systems (5-foot bed)		
Prebake	87 1/	98 1/
VSS Soderberg	87 1/	98 1/
HSS Soderberg	81 1/	98 1/
Secondary Systems (No Primary) (3-foot bed)		
All Potlines	84 2/	99 2/

1/ Equipment manufacturers estimates
2/ Industry reported data for prebake application

k) Floating Bed Scrubber

The floating bed scrubber is a special case of the packed bed scrubber concept in which the packing consists of hollow plastic spheres, approximately 1.5 inches diameter, buoyed and agitated by the rising effluent gas stream. Scrubbing liquor flows down through the bed carrying away the collected particulate and dissolved gas. Although the typical unit has only one stage, two or more may be used. One example of a single-stage floating bed scrubber uses perforated grid plates 18 inches apart caging a 12-inch bed of balls when they are at rest. At normal gas velocities, 400 to 600 feet per minute, and 10 to 20 gallons per minute liquor flow per square foot of scrubber cross section, the gas pressure drop ranges from about 2 to 6 inches water gage.

The self-cleaning action of the balls rubbing against each other makes the floating bed scrubber suitable for applications in which the particulate pollutant may have sticky or flocculent characteristics which could plug a fixed bed scrubber. HSS Soderberg potlines release tarry mists which have been controlled successfully in a foreign installation by floating bed scrubbers obtaining 90 percent total fluoride and 98 percent HF removal. 5.25/

The VSS Soderberg Sako plant at Sundsvall, Sweden, uses floating bed scrubbers on both cell gas or primary collection streams (Figure 5.16) and on potroom or secondary streams. The operators report 78 percent removal efficiency of solids and 97.5 percent of total F with two-stage scrubbers used for primary system control. See Figure 5.16. In the secondary system with single-stage scrubbers, Figure 5.17, they report 70 percent removal of solids and 87 percent of total F. Operating conditions are given in Table 5.8. 5.4/

One prebake plant in the United States uses floating bed scrubbers. The operators report HF removal efficiency in the high nineties. At another plant, floating bed scrubbers are installed on HSS Soderberg lines.

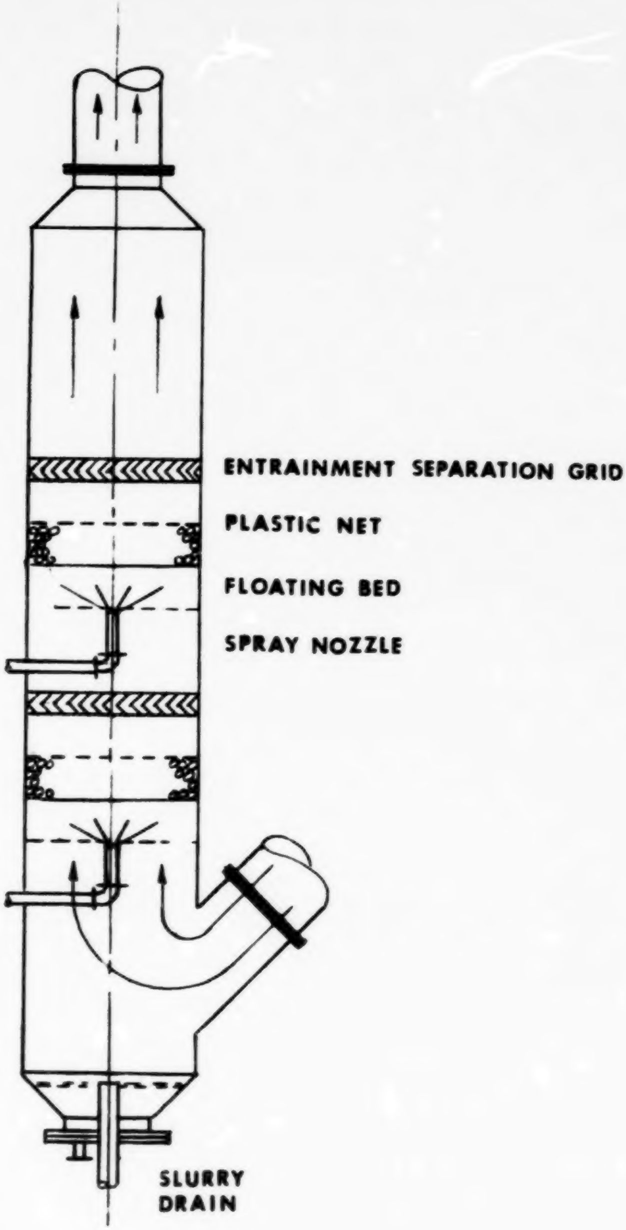
1) High Pressure Spray Screen

The high pressure spray screen wet scrubber is characterized as having high pressure liquor sprays which impinge on a grid or screen to bounce off and provide violently agitated mixing between the liquor and gases passing through the spray and screen. Figure 5.18 illustrates one such scrubber using 200 psig cocurrent sprays striking a membrane.

Results of pilot scale tests of high pressure spray screens on HSS Soderberg primary effluents using river water as scrubbing liquor are shown in Table 5.9. Removal efficiencies for particulates, especially the total solids which are primarily non-fluorine, are lower than might be expected. This may be attributable to the suspected tendency of HSS hydrocarbons to interfere with wetability of particulates. Undocumented tests on prebake effluents are reported to show the same or slightly

FIGURE 5.16

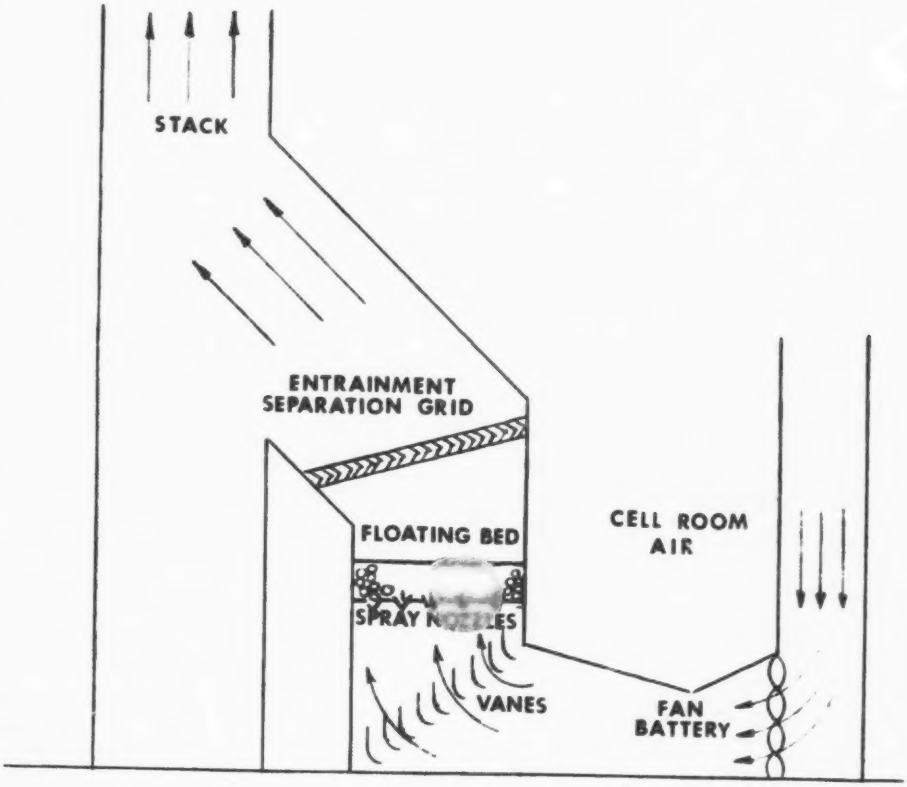
FLOATING BED SCRUBBER IN PRIMARY VSS SODERBERG SERVICE


ENTRAINMENT SEPARATION GRID
PLASTIC NET
FLOATING BED
SPRAY NOZZLE
SLURRY DRAIN

Source: Ref. 5.4/

FIGURE 5.17

FLOATING BED SCRUBBER IN SECONDARY VSS SODERBERG SERVICE

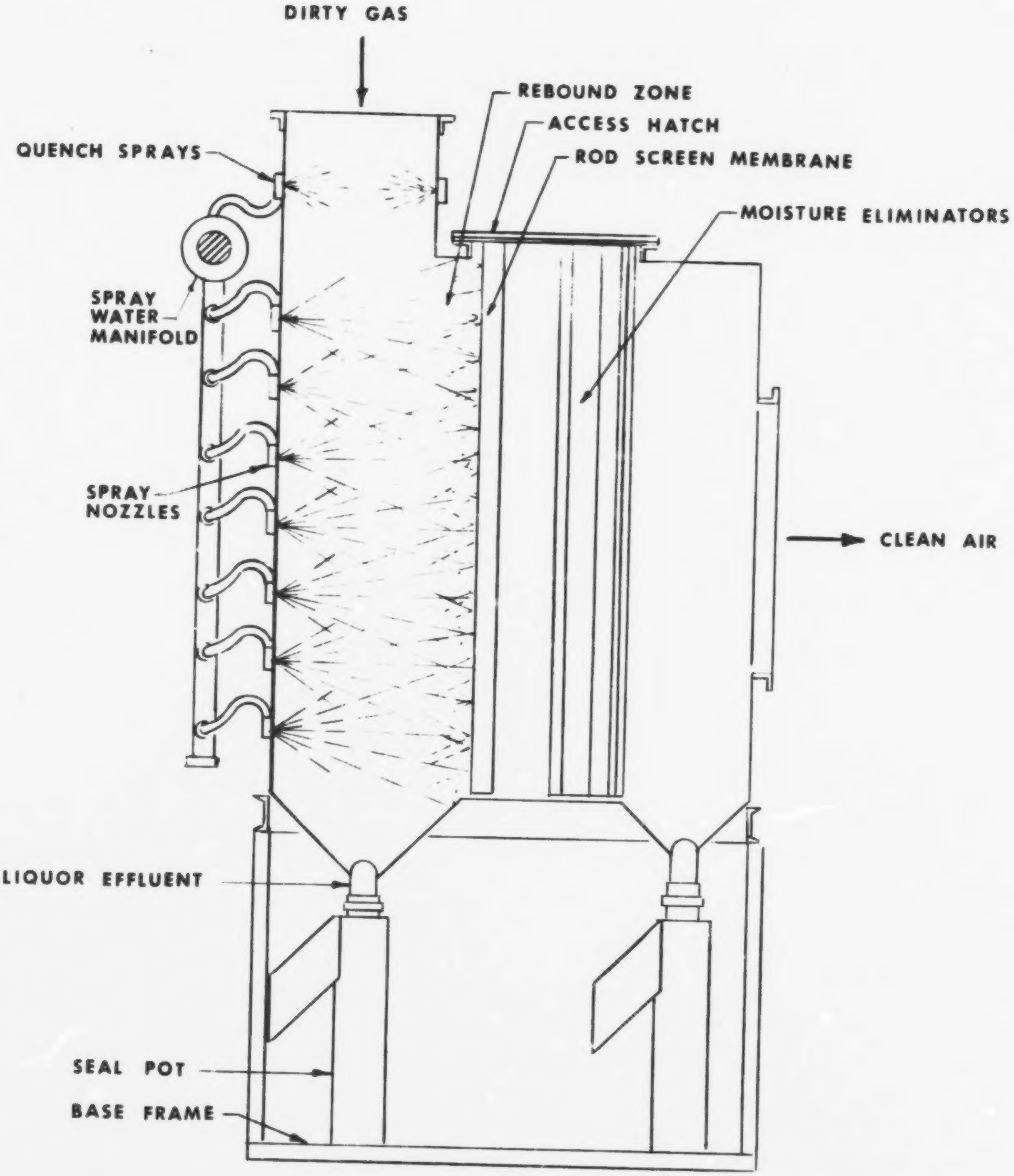

STACK
ENTRAINMENT SEPARATION GRID
FLOATING BED
SPRAY NOZZLES
VANES
CELL ROOM AIR
FAN BATTERY

Source; Ref. 5.4/

Table 5.8 - GAS CLEANING OPERATING PARAMETERS FOR SAKO, SUNDSVALL SWEDEN PLANT USING FLOATING BED SCRUBBER FOR VSS SODERBERG SERVICE 5.4/

	Primary	Secondary
Gas Flow, scf/lb Al	212	31,750
Water Flow, gal/Mscf	10.9	3.1
Pressure Drop		
Scrubber, in. water	5.1	0.59
Total, in. water	27.6	0.99
Sprays, psi	7.1	17.1
Contacting Power		
Gas, HP/Mcf	0.8	0.0925
Liquid, HP/Mcf	0.045	0.0370
Total, HP/Mcf	0.845	0.1295
Removal Efficiency, %		
Solids	78	70
Fluorides	97.5	87

FIGURE 5.18
HIGH PRESSURE SPRAY SCREEN


DIRTY GAS
REBOUND ZONE
ACCESS HATCH
QUENCH SPRAYS
ROD SCREEN MEMBRANE
MOISTURE ELIMINATORS
SPRAY WATER MANIFOLD
SPRAY NOZZLES
CLEAN AIR
LIQUOR EFFLUENT
SEAL POT
BASE FRAME

COURTESY KREBS ENGINEERS

Table 5.9 - PILOT SCALE TEST RESULTS - HIGH PRESSURE SPRAY SCREEN ON HSS SODERBERG PRIMARY SYSTEM 5.28/

Scrubbing Stages	Fresh Water		Removal Efficiency, %		
	Total gpm	Gal/Macfm	HF	Solid F	Total Solids
Single	26	5.7 to 17	95.3	82.7	71.6
Two	38	8.3 to 25	96.6	81.2	74.4
Three	50	10.9 to 33	98.4	86.5	77.3

Operating Parameters

Spray Pressure - 200 psig

Water Quantities - 14 gpm prequench, 12 gpm per stage

Superficial Gas Velocity - 250 to 767 feet per minute higher removal efficiencies for total fluoride. These test results are combined and interpreted to yield the HF and solid F removal efficiencies used in the primary systems model analysis of Section 8.

Table 5.10 shows results of test work with single and three-stage high pressure spray screens treating HSS Soderberg primary effluents after they had been treated by a spray tower.

m) Other Wet Scrubbers

There are a number of other wet scrubbing devices which have been used to remove particulates and soluble gases from an effluent stream. Some of these have been applied to domestic aluminum reduction plant effluents and have been replaced by other equipment. Others have been reported to be in use in overseas plants, but the information concerning them is open to question. The equipment has not been widely adopted in the industry.

i. The Wet Centrifugal or Multivane Gas Scrubber consists of a tower with two or more vane assemblies which impart a swirling action to dust-laden gas passing upward through them from a bottom inlet. Scrubbing liquor is distributed through low pressure sprays over the lower vane assemblies, forming a turbulent layer of liquid in which fine particulate are absorbed as the gas passes through. Liquor flows down through the vane assembly, wetting all surfaces, and passes through a gas inlet region at the bottom of the tower where the heaviest particles in the gases are removed. Particulates leave the system as a slurry from the conical bottom of the tower. A vane-type mist eliminator at the top tends to prevent droplets leaving with the exit gas.

The multivane wet centrifugal scrubber was applied to a domestic VSS Soderberg potline but has been replaced with higher efficiency scrubbers. No performance data are reportable.

ii. Dynamic Wet Scrubbers for particulate control have been developed in several configurations. Means are provided to wet the blades and case of a high speed gas fan or blower which mixes gas, dust and scrubber liquor in extreme turbulency to force dust particles

Table 5.10 - TEST RESULTS - HIGH PRESSURE SPRAY SCREEN AS SECOND STAGE SCRUBBER, HSS SODERBERG PRIMARY SYSTEM 5.28/

Single Stage

Test No.	Capacity acfm	Fresh Scrubbing Water Temp. °F	Fresh Scrubbing Water Flow gpm	Fresh Scrubbing Water Pressure psig	Removal Efficiency As Total F %
1A	3000	58	30	200	86.71
2A	3000	58	30	200	86.67
3 Stages					
1B	3000	58	60	200	89.00
2B	3000	58	60	200	89.00

into the liquid. One embodiment of the dynamic scrubber is as a second stage integral with a multivane wet scrubber. Gas, dust and liquid droplets from over the vane assembly are drawn into a centrifugal fan where more liquor is introduced at the hub. The fan discharges into a cyclonic mist eliminator from which gas exits at the top and liquor drops down to the vane assembly. The scrubber is not known to have been applied in the aluminum industry.

iii. Self-Induced Spray, or bubble type scrubber is one in which dust-laden gas is forced down into a pool of scrubber liquor forming small bubbles with violent agitation. This type of scrubber is particularly applicable to dusts which are sticky, since the equipment has no close clearances, grids, or surfaces which could built up deposits and plug. It has been applied successfully to VSS Soderberg and bake plant effluents but no performance data are reportable.

iv. The Sieve Plate Tower accomplishes its scrubbing action by bubbling the effluent gas stream up through flooded perforated plates which retain layers of scrubber liquor a few inches deep. Liquor is introduced by sprays into the upward moving gas stream and overflows from an upper to a lower stage plate at a controlled rate, carrying the captured particulates finally to a sump at the bottom of the tower.

Three and four-stage sieve plate towers have been applied to VSS Soderberg effluents at a smelter in Norway. Although data are incomplete, these installations are reported to achieve removal efficiencies of 70 percent on total particulate, 80 percent on solid fluoride and greater than 97 percent on HF. 5.29/ Later tests were reported to achieve as high as 97 percent on water soluble fluoride and 99.3 on HF. 5.7/

v. The Wet Impingement Scrubber Tower contains flooded perforated plates somewhat similar to those of the sieve plate tower, but close to and facing the discharge of each orifice is a wetted surface against which the gas strikes before turning and bubbling up through a layer of scrubber liquor on top of the plate. Sprays under the plates introduce water to wash particulates from the impingement surfaces.

The wet impingement scrubber probably could be used in potline effluent service but no report of such installation or test has been found. One test on bake plant effluent was unsuccessful; the scrubber plugged.

n) Incinerators

Unburned pollutants in effluent streams from anode bake plant ring furnaces may include particulate carbon, particulate hydrocarbons, tar mists and combustible gases, but the concentrations are too low to support combustion. A gas-fired incinerator or burner has been proposed to control these pollutants but no application in the aluminum industry has been made to date.

References - Section 5

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6.0 Source Sampling, Ambient Air Sampling and Analytical Techniques

The effective management of air pollution abatement in connection with the production of aluminum requires reliable information on the effluents and emissions of the plant and the effects of plant emissions at locations outside the plant property. Source sampling and analysis provides the data with which to evaluate the performance of pollution generating processes and the equipment used to collect and remove pollutants from exit streams. Ambient air sampling provides quantitative data on the concentration of specific pollutants at locations outside the immediate plant site.

This section of the report presents a brief introduction to some of the problems and procedures presently associated with sampling technology.

Table 6.1 indicates the orders of magnitude of total fluoride concentrations representative of the various samples which may be obtained in source and ambient air testing.

Table 6.1

Typical Total Fluoride Concentration
(Micrograms per Cubic Meter)

Primary Effluent	120,000 1/
Controlled Primary Emission	12,000 1/
Secondary Effluent	600 1/
Controlled Secondary Emission	240 1/
Ambient Air	0.1 2/

1/ Derived from Industry Questionnaire data.

2/ Approximate limit of analysis 6.5/.

6.1 Emission Sampling and Analytical Techniques

The procurement and analysis of data with which to determine the effectiveness of pollution abatement systems in the primary aluminum plant presents a number of problems of sampling which are difficult to solve. These problems are concerned primarily with obtaining representative samples of pollutants from large volume, low velocity air flows in secondary emissions, particularly in unpowered roof monitors. They are also complicated, in some streams, by water saturation and mist carryover from wet scrubbing operations, and also by cyclical or erratic condtions in the potrooms which result in non-uniform content of the gas system.

In plants where primary collection is employed, the larger portion of the total emissions occurs in relatively low flow, high velocity exhausts, and a good degree of confidence can be placed in the results of the sampling, reducing the probable errors in total emissions determination introduced by less dependable sampling of the secondary volumes.

Emission analysis needs to discriminate between gaseous and particulate compositions of the emissions, and this is complicated by the high reactivity of the gaseous fluorine compounds. The usual chemical analysis techniques cannot distinguish between fluoride originating from HF or SiF_4 and that originating from dissolved solids, cryolite or aluminum fluoride, so where discrimination is required, special techniques are employed to collect gaseous fluorides and solids separately.

Another problem is to provide information from emission sampling which can be used to correlate particulate quantity in emissions with ambient dust fall at points removed from the source. Data on particle size and settling velocity obtained by aerodynamic sizing of particulates in the emission sample will assist in this correlation.

The current practices for handling these problems are discussed in general terms. Appendix 6A contains information concerning specific sampling and analysis procedures employed at several aluminum smelters. Although all companies obtain samples in technically acceptable ways, their methods, types and materials of construction of equipment, and analytical methods differ enough that results from one company may not be directly comparable with those from another. Standardization of sampling and analysis procedures would be desirable.

6.2 Source Sampling - Primary Systems

Where primary collection systems are used on potlines, the effluents and emissions may usually be sampled in the ductwork of the control equipment, and as such present no particularly difficult problems of sampling other than those which may be purely mechanical. The compositions of the gas flows are reasonably uniform over long time periods and velocities are within ranges which may be determined with accuracy for flow calculation.

6.2.1 Sample Extraction

Representative samples are extracted from the gas stream at an isokinetic rate. Simultaneous total flow rate determinations permit relating the measured quantities of collected pollutants with the quantity of air flow and, therefore, with aluminum production.

Flow Rates

Quantification of sampled pollutant to determine total emission and relate it to aluminum production requires measurement of the volume flow rate in the sampled duct. Although high velocity ducted gas streams may be metered accurately with calibrated orifice plates or venturi restrictions and manometer pressure gages, the gas streams of most primary systems in aluminum smelters flow at such velocities that determinations by Pitot-static tube and differential pressure manometer are usually preferred. The Pitot-static tube measures velocity pressure which is converted to the local gas velocity through use of the gas density by the relationship,

$$V = C\sqrt{\frac{2g\Delta p}{\rho}}$$

where:

C = experimentally determined coefficient, near unity

Δp = velocity pressure

ρ = gas density

g = gravitational constant

Velocity measurements may be made by traversing the duct, (dividing the duct into a number of equal cross sectional areas or annuli and determining the total flow as a sum) or by making a single velocity determination at the center of the duct and multiplying by an arbitrary factor to correct this reading to an average velocity across what is usually assumed to be a fully developed turbulent flow profile. The former method, while more laborious, is the more accurate.

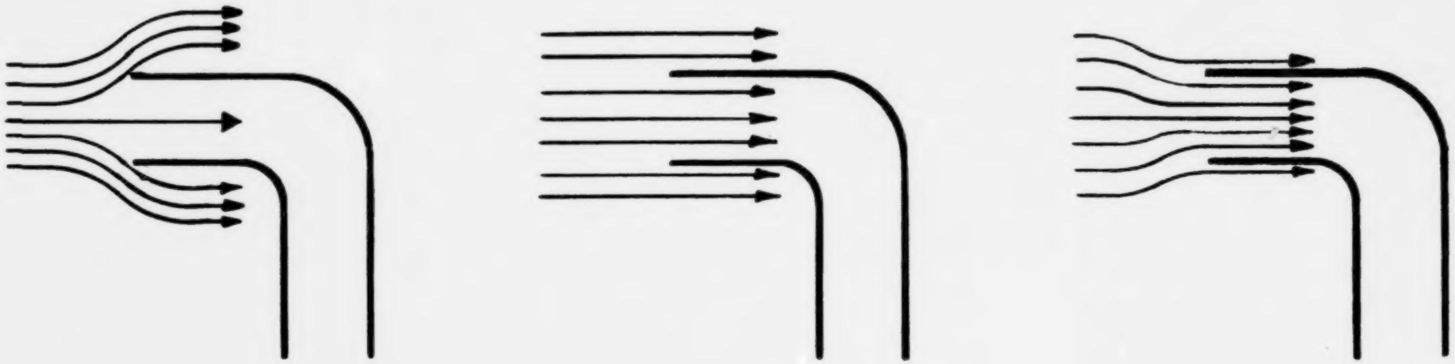
Because of fluctuations in flow conditions caused by cell operations over a period of time, multiple flow measurements are required to obtain acceptable averages.

Sampling Rates

Isokinetic flow conditions in the sampling tube are necessary if the ratio of solids to gas in the sample is to equal that ratio in the gas stream. Isokinetic conditions are realized when the sampling flow rate and the inlet diameter of the sampling tube are adjusted so that the gas velocity entering the tube equals the stream velocity at the location of the sampling tube inlet. When gas streamlines bend, entrained particulates tend to continue straight, and it can be visualized from Figure 6.1 that too slow a sampling rate will result in a sample which is relatively richer in particulates than the main gas stream; and sampling too fast will draw in a gas stream relatively lean in particulates.

FIGURE 6.1

Gas Streamlines in Isokinetic and Improper Sampling



Sampling Too Slow

Isokinetic

Sampling Too Fast

Sampling time must be long enough to ensure that the collected sampl is representative of long-time average conditions and is not atypical because of disturbances caused by periodic pot working or anode replacement. Three hours to three days of continuous or frequent intermittent sampling in one location have been reported as industry practice.

Dew point control in a sampling probe is often required to prevent the condensation of water vapor within the tube or on filters. Electric resistance or radiant heaters on the sample tube, or the placement of the particulate filter assembly within the main duct being sampled, can overcome difficulties arising from humid gas streams.

6.2.2 Sample Recovery

The equipment used for extraction of the sample from the stream flow at the positions, velocity, and time required to obtain representative samples of the total flow, includes in sequence the sample probe, mist eliminator, particulate separator, gas train, gas flow meter, and gas pump. The latter is controlled to aspirate the rate of gas sample corresponding to isokinetic flow, as determined by conditions of gas flow and temperature, and by size of sample probe.

There are two types of fluoride, particulate and gaseous, in the emissions from aluminum reduction plants which have quite different properties as to air pollution, and which therefore require separation in the emission sample.

Particulate separation may be accomplished by some type of filtration through porous media, by cyclonic separation of relatively coarse particles, or by settling out from the sample stream in specially designed equipment. In the gas concentrations typical of primary systems source sampling, the effect of HF adsorption on collected particulates may be unimportant, 6.1/, and may be neglected. This may not be true for low concentrations of pollutants typical of ambient air or secondary system sampling. Systems which attempt the removal of particulates before the gas adsorber have been found to yield misleading information because some of the HF is collected on trapped particulate and reports out of the analysis as solid F.

Total particulates separated by these devices are weighed, usually indirectly by tare differential of the collectors, to determine total dust loadings.

Gas sampling trains collect gaseous effluents usually by impingement in liquid filled impingers, but sometimes, especially in ambient air sampling, by chemical adsorption on treated filters or by adsorption on alkali coated tubes. Samples may be collected in containers which are used to transport unaltered gas samples to the analytical laboratory.

Appendix 6A, Sections 6A.1 through 6A.5 describe sampling trains and analytical techniques used at several aluminum smelters for source testing.

6.2.3 Sample Treatment

Particulate size analysis and aerodynamic size properties may be important in establishing a correlation between emission rate and effective dust fall as measured in ambient air quality evaluation.

Among the devices used to make this particle size distribution analysis, the Andersen sampler is simple and effective for measuring equivalent aerodynamic diameter. In its usual form a series of perforated plates will separate the particulate into eight aerodynamic size ranges, from 7.7 microns and above on the first stage down to 0.47 micron on the eighth stage. Particulates finer than 0.47 micron are collected on a backup filter. John Nan-Hai Hu 6.2/ describes development work in which an Andersen sampler was modified to extend the lower range to 0.17 micron by changing the flow rate and adding filter paper baffles to inhibit bouncing of particulates off the collection surfaces.

6.3 Source Sampling - Secondary Systems

Collection and analysis of samples of emission from controlled secondary systems present problems of a different order of magnitude from those of primary system emissions.

Pollutant loadings of the air streams are often much less than 5 percent of those of primary emission streams, and total air flows are some ten times greater. Unpowered flows pass through very large cross sectional areas at very low velocities, making it difficult to find suitable sampling locations as well as reducing the accuracy with which measured flow determinations can be extrapolated to account for total air flows.

Low loadings result in long sampling periods to collect significant amounts of emissions, increasing the difficulty of maintaining constant sample extraction rates and accuracy. Cyclical operating disturbances in the potroom can contribute to variations in the secondary loading which require prolonged sampling periods to collect representative samples.

6.3.1 Methods of secondary sampling may follow three different routes, each with advantages and shortcomings.

The most reliable but most costly method requires a number of sampling stations arranged so that their aggregate results will fairly represent the total emission from a whole secondary system. A single cell-room building may be 1200 feet long with 12,000 total square feet of secondary controlled exhaust openings. Total flow rate may be two million cubic feet per minute, corresponding to an exit velocity in the order of three feet per second. With a velocity pressure of only a few thousandths of an inch of water, sensitive anemometers rather than Pitot tubes are used to measure flow rate and overall accuracy is poor. However, four or more sampling stations on one building taking simultaneous samples over periods of six hours or more can yield useful data if sufficient care is exercised in selecting sampling locations.

A second method of sampling roof emissions uses multiple fixed sampling points connected by ducting to draw a simultaneous composite sample to a convenient location. This type of sampling is inexpensive when compared to the effort involved in collecting samples by alternate means. The cost of a manifold system is in the vicinity of $10,000. Also, some operators believe it is better to adjust flow to an average of

10 sample points determined by previous data than to consider each sampling point individually because of the wide fluctuation in flow at a given point from minute to minute.

A somewhat inferior alternative to simultaneously sampling a number of points uses a single sampling device moved to each of several stations in turn. The principal practical disadvantage of this technique is that, for a given elapsed time, the total number of data is less than for several simultaneous readings.

6.3.2 Sampling trains for secondary testing are similar to those used on primary streams. However, the fact that pollutant concentration may be as low as 0.5 percent of primary stream concentration makes the inherent accuracy of analysis low compared with primary measurements.

6.4 Costs and Manpower Requirements, Source Sampling

An appreciable cost (some $40,000 per potroom) may be involved in supplying sampling platforms the full length of a potroom roof monitor, including access ladders and electrical wiring. The cost for sampling stations at stack sources will vary widely dependent on the degree of accessibility, but a typical platform station might cost $10,000-$25,000 with support scaffolding and access.

Sampling manpower requirements include technicians, analysts, and a supervisory engineer. A four-man group is used by some plants, and carries out routine pollution control duties in addition to intermittent intensive sampling campaigns. Operating cost for such a group could be some $60,000 per year.

One typical fluoride control department spends about $1,000 per year for replacement of equipment, and some $20,000 per year in research on various phases of fluoride control by university and industrial research organizations.

At the other end of the scale, the major multi-plant aluminum producers maintain very large central research and development groups which include fluoride control work as a part of their activities supporting the efforts of the plant operating staff. No meaningful figures were obtained for the total annual industry expenditure for fluoride control, but it is certainly very substantial.

6.5 Analytical Determination of Fluorides

Quantitative fluorine analysis of the particulate and gaseous components of the emission samples is carried out by several methods and techniques which are authoritatively summarized in complete detail by the recent (1968) publication "Intersociety Committee Manual of Methods for Ambient Air Sampling and Analysis" 6.3/. The section of this procedure concerned with fluorine analysis describes fluoride ion isolation by the techniques of Willard and Winter distillation, ion exchange, and diffusion. It includes the quantitative determination of fluoride titrimetric and spectrographic methods.

A later development has been the availability of the fluoride ion activity electrode, the use of which is analogous to hydrogen ion determination by pH meter.

6.6 Ambient Air Sampling

The foregoing discussion has been concerned with source sampling and analysis, testing done at a smelter control system to determine effluent and emission quantities and to evaluate the performance of pollution abatement equipment. Under these conditions, gas streams are usually moving at finite and measurable velocity so that isokinetic sampling is important and the pollutant concentrations are usually relatively high. Ambient air testing, on the other hand, is used by several aluminum smelters to determine very dilute concentrations of particulate and gaseous fluorides in the air surrounding smelter sites. Only the finest particulates remain suspended and isokinetic sampling is not applicable in ambient air sampling.

Whereas source sampling is usually conducted on a campaign basis with close attention given to controlling sampling rate and measuring flow conditions over a period of a few hours, ambient sampling may be automated to the extent that the apparatus can run unattended for long periods of time.

The Boyce Thompson Institute for Plant Research, Inc., among others, has done a considerable amount of research and development work on ambient sampling and analysis for fluorides, and they have attempted to correlate ambient and dust fallout fluoride levels with damage to various kinds of plant life. References 6.4/ and 6.5/ report some of their work.

Three different kinds of sampling train have gained acceptance for ambient sampling, namely:

1) The filter and wet impinger type, also used in source sampling
2) A dual tape filter sampler in which an acid-treated tape captures particulates and an alkali-treated tape captures HF
3) A sodium bicarbonate coated tube for HF adsorption followed by a filter.

The Halogen Subcommittee of the Intersociety Committee, 6.3/ and a Task Group on Fluorides organized by the ASTM has studied various methods of sampling and analyzing ambient air for fluorides and has prepared descriptions of technique following several alternative methods. Reports are expected to cover the above three sampling methods and reviews of laboratory and semi-automatic methods of fluoride analysis of collected samples.

6.7 EPA Sampling and Analytical Techniques

Source tests were conducted in 1972 on selected plants by a contractor, EPA, or a combination of both. Analysis for fluorides and particulate material for the first two plant tests was done by the contractor; the rest of the analytical work was conducted in EPA laboratories.

Where possible, sampling and analytical procedures were used that conformed to EPA Methods 5, 6, and 7 (determination of particulate, sulfur dioxide, and nitrogen dioxide emissions, respectively, from stationary sources) as described in the Appendix to the December 23, 1971, Federal Register (Volume 36, Number 247). Measurements of oxygen (O_2), carbon dioxide (CO_2), and carbon monoxide (CO) were conducted with an Orsat analyzer.

Organic particulates were determined from the impinger solution by extracting, first with ethyl either and then with chloroform, and drying the extract to a constant weight.

Emission samples from inlets and outlets of primary control systems were collected isokinetically for fluoride analysis with the sampling train described in EPA Method 5, and the stack was traversed in accordance with EPA Method 1, "Sample and Velocity Traverses for Stationary Sources." However, some source tests were conducted using non-EPA methods that were similar to techniques used by the company.

When possible, the primary and secondary systems were sampled simultaneously. Secondary air flow measurements were provided by the company and used by EPA. When emission samples upstream and downstream of a control device could not be taken simultaneously, sequential sampling was accomplished as quickly as possible. Length of sampling time varied from 2 to 24 hours on primary systems and from 8 to 24 hours for secondary emissions.

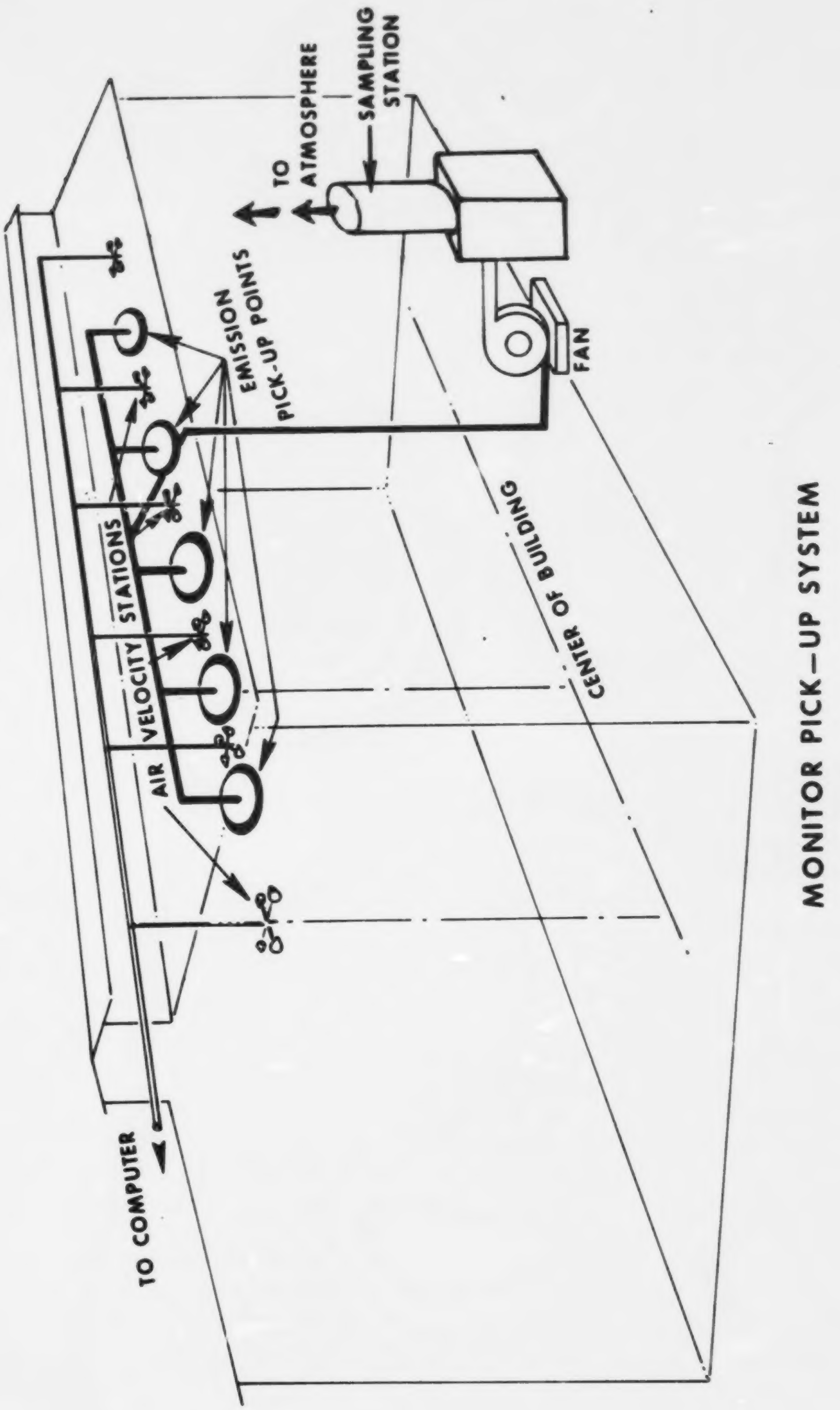
Special sampling techniques were required to measure emissions of exit gases where we could neither traverse nor sample isokinetically. These special sampling techniques were used to sample secondary emissions from some roof monitors. Some plants used a control system, others did not. Traverse sampling was not practical because of the cross-sectional area to be covered and location of the sampling stations. Isokinetic sampling conditions were not ideal because of the low air velocity, which lowers the air sampling rate below the point of efficient collection of the pollutant (fluoride) in the impinger section of the EPA train. Therefore it was decided to sample at a constant rate of 1 cubic foot per minute at a single point, close to the center of the air stream, to reduce interferences. This single-point method is a reasonable sampling technique since about 70 percent of the particulates released at the cell could be less than 3 microns in size. A very important criterion was to ensure that the sample rate permitted maximum efficiency of the impinger section of the sampling train. EPA felt these sampling techniques for testing roof monitors were reasonable under the circumstances, but because they were subject to error, EPA feels that the results are satisfactory only as an estimate of emissions.

A second and more elaborate method of sampling the monitor was provided by one company that has installed a multipoint sampling system in the roof monitor (Figure 6.2). Continuous air samples were drawn through the common manifold to a discharge stack. Standard sampling techniques could be performed at the stack and the results prorated over the total air flow out the monitor. Air flow through the roof monitor was simultaneously measured at many points with anemometers. The anemometers were monitored by a computer that provided air velocity readings every few minutes for an accurate measurement of air flow during the sampling period. This system was attractive because it permitted increased confidence in the sampling technique. Results of this type of test on a secondary system should be more reproducible than those from the single-point nonisokinetic sample. The company reports excellent correlation between this sampling method and elaborate manual techniques for sampling in the monitors.

Samples were analyzed for both water-soluble and water insoluble fluorides. The water-soluble fluorides were determined by the SPADNS-Zirconium Lake Method, after the sample was first distilled with sulfuric acid.

FIGURE 6.2

SECONDARY SYSTEM SAMPLING ARRANGEMENT


TO ATMOSPHERE
SAMPLING STATION
EMISSION PICK-UP POINTS
FAN
AIR VELOCITY STATIONS
CENTER OF BUILDING
TO COMPUTER
MONITOR PICK–UP SYSTEM

Water-insoluble fluorides were also determined by the SPADNS method after the sample had been fused with NaOH. These are both standard fluoride analytical techniques used for many years by industrial plants and enforcement agencies.

The proposed EPA sampling and analytical technique for fluorides (Method 13) is given in Appendix 6B. This may be subject to some minor changes before Method 13 becomes part of the Federal Register in its final form. The proposed Method 13 for fluorides is included in this report in its present form so that industry may become familiar with the procedures.

The results of EPA source sampling program are reported in Section 7.5 of this report.

References - Section 6

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Section 7

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7.0 Reported Industry Effectiveness and Costs of Air Pollution Abatement

Quantitative data on aluminum smelter effluents and emissions have been collected from responses to a comprehensive questionnaire distributed to all primary aluminum producers in the United States, and from references in the technical literature. The responses covered the operations of all but one plant in the United States, and varied in completeness of detail furnished. Technical literature reference and data on emission control were concerned largely with operations in seven European plants.

The questionnaire information was furnished under an agreement to preserve its confidentiality with respect to individual plants and to report only composite averages representative of industry practice.

7.1 Industry Emission Control Practice

Almost no data have been reported for the quantities of effluents and emissions from aluminum smelters for process areas other than the potlines.

Materials handling operations in the potrooms and various process operations in carbon plants evolve dusts of alumina, cryolite, carbon and other materials in minor quantities. These effluents are normally collected in baghouses, cyclones or dry electrostatic precipitators as a means for conserving process materials and maintaining clean working conditions within the plants.

Bake Plant Emissions

Anode baking furnaces evolve objectionable quantities of smoke, some SO_2, and small amounts of fluorides. These effluents are sometimes treated in scrubbers or other control equipment, mainly to remove visible components of the smoke. Only limited quantitative information has been found to be available.

From the segment of the industry operating anode baking furnaces, information on bake plant effluents was received which represented 62 percent of the total aluminum production by prebake anode reduction plants. The weighted averages of the reported data indicated that the effluent flow rate from a typical ring furnace is of the order of 214 standard cubic feet (at 70°F) per pound of prebake aluminum plant capacity, with gas loadings of 0.015 grain total gaseous fluoride and 0.085 grain total particulate per standard cubic foot. Fluoride in bake plant effluents is reported to be negligible amounting to only about one percent of the total smelter plant fluoride effluent. Emission data on anode bake plants was not reported by the industry, although some 43 percent of the bake plant capacity has some sort of emission control, much of it experimental.

Based on observations and impressions gained through industry and suppliers contacts, an assumption has been made that a removal efficiency of 96 percent on gaseous fluoride and 75 percent on particulates can be achieved on bake plant effluents. It is estimated that some 40 percent of total bake plant effluents are currently treated with this order of control.

While tunnel kilns are reported to produce lower loadings of effluents than ring furnaces, the proportion of total prebaked anodes now baked in tunnel kilns is small enough (perhaps 7 percent) that to disregard this difference does not affect the limited accuracy of the calculations made.

The presence of fluoride compounds in bake plant effluents can be largely controlled by more complete cleaning of bath material from spent anode butts which are recycled through the anode baking circuit, since this material is the largest source of fluorine in the process.

Potroom Emissions

Tables 7.1 show a breakdown of potline effluents and emissions as reported for a composite of United States smelter experience. All quantities are expressed as pounds of pollutant per 1000 pounds of aluminum produced (equivalent to kg/tonne). Values have been computed by summing the total annual quantities of pollutants calculated for each of the companies responding to the industry questionnaire, and dividing by the annual aluminum production of those companies.

The fact that the values shown in this table for "total F" does not equal the sums of their respective "solid F" and "HF" values results from the fact that not all questionnaire respondents provided breakdowns of solid and gaseous fluorine. As much of the reported data as possible was used.

Tables 7.2 show effluents and emissions as reported in the literature for seven European aluminum smelters; these data may be compared with corresponding weighted average data for all the United States plants responding to the industry questionnaire.

Table 7.1a - U.S. INDUSTRY REPORTED EFFLUENT CONTROL

PREBAKE POTLINES

	Percent Tons Reporting	Lbs/1000 lbs Aluminum		
		High	Wtd Avg	Low
Total Solids				
Effluent	60	88.6	47.2	22.5
Primary Collection	83	84.5	43.8	21.6
Secondary Collection	65	7.8	4.0	2.0
Primary Emission	76	12.5	4.6	1.1
Secondary Emission	65	7.8	4.0	2.0
Total Emission	65	16.3	8.1	3.5
Overall Control Efficiency			81%	
Solid F				
Effluent	69	14.8	10.2	4.7
Primary Collection	76	14.0	9.2	4.0
Secondary Collection	65	1.6	0.7	0.6
Primary Emission	58	3.7	1.4	0.7
Secondary Emission	65	1.6	0.7	0.6
Total Emission	47	4.4	2.5	1.8
Overall Control Efficiency			75%	
HF				
Effluent	65	17.4	12.4	8.1
Primary Collection	76	17.0	10.6	6.0
Secondary Collection	65	1.2	0.5	0.2
Primary Emission	52	9.8	0.9	0.1
Secondary Emission	65	1.2	0.5	0.2
Total Emission	47	3.2	1.5	0.5
Overall Control Efficiency			88%	
Total F				
Effluent	65	33.0	23.2	12.8
Primary Collection	80	31.0	19.8	15.4
Secondary Collection	65	1.7	1.3	1.0
Primary Emission	80	12.8	1.8	1.3
Secondary Emission	65	1.7	1.3	1.0
Total Emission	65	5.1	4.3	1.4
Overall Control Efficiency			81%	

Table 7.1b - U.S. INDUSTRY REPORTED EFFLUENT CONTROL

VSS SODERBERG POTLINES

	Percent Tons Reporting	Lbs/1000 lbs Aluminum		
		High	Wtd Avg	Low
Total Solids				
Effluent	-	-	39.2	-
Primary Collection	-	-	22.0	-
Secondary Collection	-	-	11.2	-
Primary Emission	89	6.5	4.4	2.2
Secondary Emission	-	-	6.7	-
Total Emission	-	-	11.7	-
Overall Control Efficiency			70%	
Solid F				
Effluent	64	5.6	5.0	2.8
Primary Collection	100	5.5	3.1	1.0
Secondary Collection	64	4.4	3.0	1.3
Primary Emission	100	1.2	0.8	0.3
Secondary Emission	64	4.4	2.9	0.8
Total Emission	64	5.6	3.8	1.6
Overall Control Efficiency			24%	
HF				
Effluent	64	17.5	15.2	10.0
Primary Collection	100	23.5	16.4	7.5
Secondary Collection	64	2.4	2.2	1.1
Primary Emission	100	1.9	0.7	0.0
Secondary Emission	64	2.4	1.6	0.3
Total Emission	64	2.5	1.6	0.3
Overall Control Efficiency			89%	
Total F				
Effluent	100	30.6	23.2	15.4
Primary Collection	100	29.0	19.5	11.6
Secondary Collection	100	6.8	3.9	2.8
Primary Emission	100	2.4	1.5	0.3
Secondary Emission	100	6.8	3.4	1.0
Total Emission	100	8.0	4.9	2.0
Overall Control Efficiency			79%	

Table 7.1c - U.S. INDUSTRY REPORTED EFFLUENT CONTROL

HSS SODERBERG POTLINES

	Percent Tons Reporting	Lbs/1000 lbs Aluminum		
Total Solids		High	Wtd Avg	Low
Effluent	93	52.0	49.2	41.8
Primary Collection	93	42.0	39.1	31.4
Secondary Collection	93	10.4	10.1	10.0
Primary Emission	93	10.1	8.9	8.5
Secondary Emission	93	10.4	10.1	10.0
Total Emission	93	20.5	19.0	18.5
Overall Control Efficiency			61%	
Solid F				
Effluent	93	8.1	7.8	7.2
Primary Collection	93	7.4	6.9	5.4
Secondary Collection	93	1.8	1.0	0.7
Primary Emission	93	3.2	2.3	1.1
Secondary Emission	93	1.8	1.0	0.7
Total Emission	93	4.2	3.3	2.9
Overall Control Efficiency			58%	
HF				
Effluent	100	14.4	13.3	12.6
Primary Collection	100	12.0	11.3	10.8
Secondary Collection	100	3.6	2.0	0.6
Primary Emission	100	2.8	1.0	0.8
Secondary Emission	100	3.6	2.0	0.6
Total Emission	100	4.6	3.0	2.3
Overall Control Efficiency			77%	
Total F				
Effluent	93	21.6	21.2	21.0
Primary Collection	93	18.8	18.1	16.2
Secondary Collection	100	5.4	3.0	1.6
Primary Emission	100	6.0	3.3	2.1
Secondary Emission	100	5.4	3.0	3.0
Total Emission	100	7.6	6.3	5.8
Overall Control Efficiency			70%	

Table 7.1d - U.S. INDUSTRY REPORTED EFFLUENT CONTROL

ALL TYPES OF POTLINES

	Percent Tons Reporting	Lbs/1000 lbs Aluminum		
		High	Wtd Avg	Low
Total Solids				
Effluent	63	88.6	47.7	22.2
Primary Collection	82	84.5	40.3	16.4
Secondary Collection	71	7.8	6.9	2.0
Primary Emission	82	24.4	5.9	1.1
Secondary Emission	71	7.8	6.4	2.0
Total Emission	71	23.5	12.3	3.5
Overall Control Efficiency			73%	
Solid F				
Effluent	72	14.8	8.8	2.8
Primary Collection	84	14.0	7.5	1.0
Secondary Collection	74	4.4	1.1	0.6
Primary Emission	75	3.7	1.6	0.3
Secondary Emission	74	4.4	1.1	0.6
Total Emission	65	5.6	3.0	1.6
Overall Control Efficiency			66%	
HF				
Effluent	74	17.5	13.1	8.1
Primary Collection	86	23.5	11.7	4.1
Secondary Collection	75	2.6	1.2	0.2
Primary Emission	75	9.8	0.9	0.1
Secondary Emission	74	2.6	1.2	0.2
Total Emission	64	3.2	2.1	0.3
Overall Control Efficiency			84%	
Total F				
Effluent	77	33.0	22.5	12.8
Primary Collection	86	31.0	19.3	4.2
Secondary Collection	79	6.8	2.3	1.0
Primary Emission	88	12.8	2.3	0.3
Secondary Emission	79	6.8	2.3	1.0
Total Emission	79	8.0	5.1	1.4
Overall Control Efficiency			77%	

Table 7.1

Notes:

1. "Percent Tons Reporting" signifies the fraction of total U.S. annual production in each potline type which contributed data used to compute the weighted average effluent and emission factors. For example, plants producing 60 percent of the total U.S. prebake potline aluminum reported data which were used to compute a weighted average of 47.2 pounds of total solids effluent per 1000 pounds of aluminum produced.

2. High and low values for individual plant factors and "Percent Tons Reporting" are given only in cases where the weighted average values are computed from three or more data.

3. Weighted average factors represent the total annual reported quantity of a given effluent or emission divided by the total annual production of aluminum corresponding to that quantity.

4. Values for "Overall Control Efficiency" for each component are calculated from weighted average factors according to the formula,

$$\frac{(\text{Effluent Factor} - \text{Total Emission Factor})}{\text{Effluent Factor}} \times 100$$

5. Collection and emission factors for those plants which use no primary collection system per se but treat all effluents passing through roof monitors, are included in the calculations for primary collection and emission factors.

6. U.S. aluminum companies reporting effluent and emission data are summarized in the following table:

Plant Type	Estimated U.S. Production 10^9 lb/yr	Reporting Data 10^9 lb/yr	Percent Reporting
PB	4.433	3.906	88
VSS	1.012	1.012	100
HSS	2.042	2.042	100
All	7.487	6.960	93

7. Data for Table 7.1 were derived from responses to the Industry Questionnaire.

Table 7.2a - REPORTED EUROPEAN EFFLUENT CONTROL PRACTICE

		Prebaked Potlines (Lbs/1000 lbs Aluminum)	
Total Solids	Plant*	A	B
Effluent		NR	NR
Primary Collection			
Secondary Collection			
Primary Emission			
Secondary Emission			
Total Emission			
Overall Control Efficiency		↓	↓
Solid F			
Effluent		8.0	8.8
Primary Collection		-	-
Secondary Collection		8.0	8.8
Primary Emission		-	-
Secondary Emission		3.8	4.5
Total Emission		3.8	4.5
Overall Control Efficiency		52%	49%
HF			
Effluent		9.6	11.0
Primary Collection		-	-
Secondary Collection		9.6	11.0
Primary Emission		-	-
Secondary Emission		0.51	0.56
Total Emission		0.51	0.56
Overall Control Efficiency		95%	95%
Total F			
Effluent		17.6	19.8
Primary Collection		-	-
Secondary Collection		17.6	19.8
Primary Emission		-	-
Secondary Emission		4.3	5.1
Total Emission		4.3	5.1
Overall Control Efficiency		76%	74%

* See notes, Table 7.2

Table 7.2b - REPORTED EUROPEAN EFFLUENT CONTROL PRACTICE

(Lbs/1000 lbs Aluminum)

	Soderberg Potlines				
	VSS				HSS
Plant*	C	D	E	F	G
Total Solids					
Effluent	17.8	36.8	63.2	NR	27.7
Primary Collection	12.2	21.0	40.0	NR	12.7
Secondary Collection	5.6	15.8	23.2	NR	15.0
Primary Emission	0.1	1.5	1.3	NR	3.8
Secondary Emission	2.8	5.2	23.2	NR	15.0
Total Emission	2.9	6.7	24.5	NR	18.8
Overall Control Efficiency	80%	82%	61%	72%	32%
Solid F					
Effluent	4.2	NR	NR	NR	NR
Primary Collection	3.0	↓	↓	↓	↓
Secondary Collection	1.2	8.8	↓	↓	↓
Primary Emission	0.02	NR	↓	↓	↓
Secondary Emission	0.60	↓	↓	↓	↓
Total Emission	0.62	↓	↓	↓	↓
Overall Control Efficiency	86%	↓	↓	↓	↓
HF					
Effluent	11.9	16.3	22.3	NR	7.1
Primary Collection	7.8	11.6	20.0	↓	5.1
Secondary Collection	4.1	4.7	2.3	↓	2.0
Primary Emission	0.01	0.17	0.46	↓	0.95
Secondary Emission	0.98	0.96	2.32	↓	2.0
Total Emission	0.99	1.13	2.78	↓	2.95
Overall Control Efficiency	92%	93%	87%	↓	58%
Total F					
Effluent	16.0	NR	NR	17.0	NR
Primary Collection	10.8	↓	↓	12.8	↓
Secondary Collection	5.2	↓	↓	4.2	↓
Primary Emission	0.04	↓	↓	NR	↓
Secondary Emission	1.60	↓	↓	NR	↓
Total Emission	1.54	↓	↓	1.0	↓
Overall Control Efficiency	90%	↓	↓	94%	↓

*See notes Table 7.2

Notes - Table 7.2

Plant Designation	Company	Lit. Reference
A	Alusuisse	7.1/
B	Alusuisse (Rheinfelden)	7.2/
C	Montecatini	7.3/
D	Pechiney (Nougeres)	7.4/, 7.5/
E	German Practice	7.6/
F	Svenska Aluminum	7.7/, 7.8/
G	German Practice	7.6/
NR	Not Reported	

7.2 United States Emissions Inventory (1970)

The emissions from the domestic primary aluminum industry in 1970 are estimated from reported industry data to have been as shown below and in Table 7.3.

	Tons Emissions (1970)		
	Potrooms	Bake Plants	Total
Total Fluorine	23,200	650	23,800
Gaseous Fluorides	10,200	600	10,800
Fluorine in Particulates	13,000	30	13,000
Total Solids	53,000	4,200	57,200

These estimates are based on a 1970 production of 4 million short tons of aluminum, of which about 2.5 million tons was produced in prebake anode plants. Reported potroom emission data were available on 84 percent of the industry tonnage. No data were reported on bake plant emissions, and the estimates given above were derived from reported data on furnace gases, the control equipment identified in individual bake plants, and estimated control efficiencies ascribed to the control systems.

A more detailed analysis of this inventory is shown in Table 7.3 which puts into focus the relative importance of potroom and bake plant control.

7.3 Emission Control Costs

The industry questionnaire requested detailed cost information for individual items of collection and removal equipment, including capital costs and breakdowns of the various elements of operating costs. From these data costs of total plant and industry emission control could be built up.

The responses to this cost request were as complete as the aluminum companies were able to provide from their records, and included nearly 88 percent of the pollution controlled aluminum production (85 percent of the total production). Dates of installation were given so that capital investments could be adjusted to terms of 1970 dollars.

Table 7.3 - ESTIMATED TOTAL INDUSTRY EFFLUENTS AND EMISSIONS (1970)

	Tons							
		Potlines			Bake Plant			
	Tons per 1000 tons Al Produced**	Controlled	Uncontrolled	Total	Controlled	Uncontrolled	Total	Industry Total
Total Aluminum Production		3,854,000	123,000	3,976,000*	1,090,000	1,435,000	2,525,000	
Effluents								
Total Fluoride	23.0	88,600	2,800	91,400	470	615	1,085	92,500
F as Gas	13.9	53,600	1,700	55,300	440	590	1,030	56,300
F as Solids	9.1	35,100	1,100	36,200	25	30	55	36,200
Total Solids	45.6	175,700	5,600	181,300	2,650	3,500	6,150	187,500
Emissions								
Total Fluorine	5.3	20,400	2,800	23,200	25	615	640	23,800
F as Gas	2.2	8,500	1,700	10,200	20	590	610	10,800
F as Solids	3.1	11,900	1,100	13,000	5	25	30	13,000
Total Solids	12.3	47,400	5,600	53,000	650	3,500	4,160	57,200
Overall Control Efficiency								
Total Fluorine		77%	-	74.6%	92.5%	-	41%	73.2%
F as Gas		84	-	81.5	95	-	41	80.8
F as Solids		66	-	64.0	80	-	45	64.0
Total Solids		73	-	70	75	-	32	69.6

* USBM est. 1970 production

**Unit effluent and emission data derived from reported controlled potline effluent data with adjustments to reconcile balances.

The details of the responses were not uniform, and interpretations were necessary to bring them to a common base and reconcile obvious discrepancies and omissions.

Escalation of reported capital costs to 1970 equivalent investment, and extrapolation to include the 12 percent of controlled tonnage not reported, resulted in the summary figures shown in Table 7.4, and in the estimate that the direct capital investment in potroom pollution control for the 1970 annual production capacity of about 4.1 million tons is about $182,000,000.

Cost data reported for investment in bake furnace emission control were incomplete and fragmentary, and did not justify derivation of an estimate of industry investment. It is certainly of a different order of magnitude and perhaps might be composed of $3.5 million for stack and collection systems required on all plants plus $1.5-$2 million for the control equipment now installed in the industry.

The annual direct operating cost ascribable to potline pollution control is estimated from reported data to be of the order of $11 million per year, with the reported range between $1.20-$6.63 per ton of aluminum illustrating the different degrees of control employed among the reporting plants. It is noted that the reported direct operating cost includes power, labor and maintenance materials only, and excludes capital charges.

The foregoing report averages for capital investment and operating costs represent direct costs. Sections 8.3 and 9.2 deal with estimated costs for model control systems using costs which include indirect installation costs at 30 percent of direct capital (purchase and direct installation). Model operating costs include capital sensitive factors amounting to 23 percent of total capital. Adjusted to include indirect charges as used in the model systems analysis, the total industry reported investment in potroom pollution control facilities would be $236,000,000 or about $57.60 per capacity ton. Similarly, if the reported $11 million annual direct operating cost is adjusted to include interest, taxes, insurance, and depreciation, it becomes about $65,000,000 or about $15.84 per ton of aluminum.

Table 7.4

INDUSTRY-WIDE COSTS FOR AIR POLLUTION CONTROL IN ALUMINUM POTLINE OPERATIONS

Component	Reported Costs in $/Ton Aluminum		
	High	Weighted Avg	Low
Reported Capital Costs 1/			
Collection Equipment	54.90	17.00	7.70
Removal Equipment	62.90	27.80	3.90
Total Control Equipment	75.20	44.30	18.10
Adjustment for Indirect Costs		13.30	
Estimated Total Capital Cost		57.60	
Reported Operating Costs 2/			
Electric Power	2.00	.89	.19
Materials	1.55	.66	.21
Labor 3/	4.66	1.19	.24
Total Operating Cost	6.63	2.61	1.20
Annualized Capital at 23%		13.23	
Estimated Total Operating Cost		15.84	

1/ Expressed as (1970) dollars per annual ton of aluminum production capacity.

2/ Expressed as dollars per ton of aluminum produced.

3/ Includes both operating and maintenance labor.

7.4 Industry Cost Effectiveness

From the reported data the United States primary aluminum industry, as a whole, is accomplishing an overall potline emission control of about 75 percent of total fluorine, 81 percent of gaseous fluorides, 64 percent of fluorine in particulates, and 70 percent of total solids, with an adjusted total capital investment of some $236 million (in 1970 dollars) and an adjusted total operating cost of about $65 million per year. The industry costs represent investment of some $58 per annual ton of capacity and total net pollution control operating costs of about $16.00 per ton of production at this level of pollution abatement.

The control now exercised results in an emission of an average of some 12 pounds total fluorine, 5.4 pounds gaseous fluorides, 6.5 pounds fluorine in particulates, and 28.6 pounds of total solids per ton of aluminum produced.

7.5 EPA Source Sampling

After the analysis and systems study of the industry-reported data had been completed, EPA carried out a program of source sampling at plants selected to represent applications of best control technology, to verify the data supplied by industry and to develop further information.

The program included source testing of potline installations at two VSS plants, three prebake plants, and one HSS plant, and source testing at the anode bake plants associated with two of the prebake plants.

The digest of the results of these tests as presented by EPA is given in this section. Data are reported in terms of pounds per ton of aluminum produced, in distinction to the units of pounds per thousand pounds aluminum produced (numerically equal to kilograms per tonne) used elsewhere in this report.

7.5.1 Description of Facilities Tested

Plant A - uses vertical-stud Soderberg cells with both primary and secondary emission control systems. When this plant was first tested, the primary control system consisted of a "bubbler scrubber" followed in series by a redwood-tower scrubber. The secondary control system consisted of a spray-screen scrubber. A_1 and A_2 are the same plant as A, but these tests were done after the company had modified the primary control system to a "bubbler scrubber" followed by a wet electrostatic precipitator. The secondary system remained a spray screen. The duration of sampling and the dates are the only differences between tests A_1 and A_2.

Plant B - uses prebake cells with a fluid-bed dry scrubber as the primary emission control system and has no secondary control. Test B_1 is a repeat source test of this plant to get more complete data. Other features in this plant that reduce emissions are the use of computerized pot lines for crust breaking, alumina additions, and minimum anode effects. The company had good pot-hooding control and a maintenance program to keep the hoods in good condition. This plant had a secondary monitor sampling and air velocity system as described in Section 6.7 on secondary emission sampling.

Plant C - uses prebake cells with both primary and secondary emission control systems. The primary system consisted of a cyclonic wet scrubber and the secondary control system was a spray screen scrubber.

Plant D - is very similar to Plant B. It uses prebake cells with a fluid bed dry scrubber as the primary emission control system and has no secondary control. Test D_1 is the average of the results of two non-EPA test methods conducted at this plant. Other features in this plant that reduce emissions are the use of computerized pot lines for crust breaking, alumina additions, and minimum anode effects. The company had good pot-hooding control and a maintenance program to keep the hoods in good condition. This plant had a secondary monitor sampling and air velocity system as described in Section 6.7 on secondary emission sampling.

Plant E - uses horizontal-stud Soderberg cells with a wet scrubber followed by a wet electrostatic precipitator as the primary emission control system. This plant had no secondary controls.

Plant F - uses vertical-stud Soderberg cells with a wet scrubber followed by a wet electrostatic precipitator as the primary emission control system. This plant had no secondary controls.

Plant G - is an anode bake plant using a wet preconditioner ahead of an electrostatic precipitator as the emission control system.

Plant H - is also an anode bake plant with a wet preconditioner ahead of the electrostatic precipitator as the emission control system. However, during EPA source tests the wet preconditioner was not operated.

7.5.2 Discussion of EPA Source Test Results

EPA conducted 20 primary inlet, nine secondary inlet, 12 controlled secondary outlet, and 10 uncontrolled secondary outlet emissions tests for total fluoride.

In addition, 24 primary and three secondary inlet and 27 primary and three secondary controlled outlet particulate tests were conducted. No uncontrolled secondary outlet particulate tests were taken.

Table 7.5 presents the results of particulate and fluoride tests conducted by EPA on potline effluents and two anode bake plants. Potline effluent emission units are expressed as pounds total fluoride or pounds particulate material per ton of aluminum produced (lb TF/TAP and lb P/TAP, respectively). Anode bake plant effluents are expressed as pounds total fluoride per ton of anode produced (lb TF/TAnP). Source tests were conducted on the inlet to the control systems and are shown on the table as primary or secondary collection. Outlet source tests are shown on the table as primary or secondary emission. The individual data points shown in the table are an average of the tests taken where more than one test was conducted. From the inlet and outlet data, efficiencies of the various emission control systems were calculated. Sampling and analytical techniques employed are described in Section 6.7. The source test data sheets in Appendix 7A give some other details on each test not shown in Table 7.5.

In Section 6.7, the potroom facilities and type of control systems for each were described. Therefore, the following discussion will just present source test results.

Table 7.5 - RESULTS OF EPA SOURCE TESTS FLUORIDE AND PARTICULATE
PRIMARY ALUMINUM INDUSTRY
lbs/Ton Aluminum*

Plant Cell Type Control (Primary) (Secondary)	A VSS BS-ST SS	A1 VSS BS-WESP SS	A2 VSS BS-WESP SS	B PB FBDS None	B1 PB FBDS None	C PB ST SS	D PB FBDS None	D1 PB FBDS None	E HSS ST-WESP None	F VSS ST-WESP None
PARTICULATES										
Primary Collection	NS	91.26 (67.60)[2]	NS	110.10	100.30	NS	72.26	NS	81.80	38.20
Secondary Collection	-	27.12 (26.68)	-	NS	NS	-	NS	-	NS	NS
Primary Emission	-	0.12 (0.11)	-	13.79	1.80	-	4.00	-	5.95	1.34
Secondary Emission	-	9.53 (5.83)	-	NS	NS	-	NS	-	NS	NS
Total Emission	-	9.65 (5.94)	-	-	-	-	-	-	NS	NS
Primary Efficiency (%)	-	99.86 (99.84)	-	87.46	98.19	-	94.43	-	92.73	96.58
Secondary Efficiency (%)	-	64.85 (78.15)	-	NC	NC	-	NC	-	NC	NC
Overall Control Efficiency (%)	-	91.85 (93.70)	-	-	-	-	-	-	-	-
TOTAL FLUORIDE (Particulates and Gaseous)										
Primary Collection	53.50	37.69	NS	NS	37.80 (48.05)	28.10	61.40	NS	46.53	NS
Secondary Collection	3.65	3.02	NS	-	1.20	9.06	1.17	NS	2.06	-
Primary Emission	1.65	0.01	0.02	-	0.14	69.64[3]	0.87 (0.49)[4]	0.35	0.41	-
Secondary Emission	1.65[1]	0.81	2.05	-	1.20	7.30	1.17	1.17	2.06	-
Total Emission	3.30	0.82	2.07	-	1.34	76.94	2.04 (1.66)	1.52	2.47	-
Primary Efficiency (%)	96.91	99.97	99.94	-	99.62 (99.54)	-	98.64 (99.23)	99.31	99.11	-
Secondary Efficiency (%)	54.79	73.17	32.12	-	NC	19.42	NC	NC	NC	-
Overall Control Efficiency (%)	94.22	97.98	94.92	-	96.89 (97.46)	-	96.89 (97.46)	97.54	94.95	-

Plant Control	G ESP	H ESP
ANODE BAKE PLANTS(5)		
Particulate Emissions	1.56	3.96
Total Fluoride Emissions	0.88	1.25

* Refer to legend following for notes.

LEGEND FOR TABLE 7.5

VSS - Vertical stud Soderberg cell

PB - Prebake cell

HSS - Horizontal stud Soderberg cell

BS - "Bubbler" scrubber

ST - Spray tower

WESP - Wet electrostatic precipitator

SS - Spray screen

FBDS - Fluid bed dry scrubber

NS - No sampling

NC - No control

(1) - Average of two tests; one test suspected to be contaminated and deleted.

(2) - Average of two tests; one test deleted due to stud blow during test.

(3) - Samples suspected to be contaminated during sampling; these plant data are suspect.

(4) - Data with two tests deleted due to suspected control system malfunction.

(5) - Anode plant emission units are lb/ton anode produced.

Plant A data show the average of three each primary and secondary inlet tests and three each primary and secondary outlet tests for fluorides. Primary collection data ranged from 42.20 to 62.30 lb TF/TAP with an average of 53.50. Primary emission data ranged from 1.28 to 1.97 lb TF/TAP with an average of 1.65. Secondary collection data ranged from 1.38 to 5.74 lb TF/TAP with an average of 3.65. Secondary emission data ranged from 1.07 to 37.20 lb TF/TAP. The 37.20 lb TF/TAP figure is not consistent with company or EPA data; it was thus deleted, and the average for the two tests is 1.65 lb TF/TAP. These high points were probably due to picking up a highly contaminated particulate or water droplet during the sampling period. The primary emission control system, from which these tests were conducted, was shut down and a new primary system installed. A_1 and A_2 represent data from the "new" plant or system.

A_1 data show three primary inlet tests for particulate ranged from 44.90 to 138.63 lb P/TAP with an average of 91.26. Three primary outlet tests ranged from 0.10 to 0.13 lb P/TAP with an average of 0.12. Three secondary inlet tests ranged from 22.38 to 30.98 lb P/TAP with an average of 27.12. Three secondary outlet tests ranged from 7.44 to 16.91 lb P/TAP with an average of 9.53. The high figures of 138.63 and 16.91 lb P/TAP came during a source test in which a stud blow occurred. Though the company states that stud blows are a rare occurrence, these figures were used in calculating the averages shown in Table 7.5.

The data shown in parenthesis in Table 7.5 for Plant A, are with the stud blow test deleted.

Test A_1 data for fluorides show three primary inlet tests ranged from 32.57 to 42.80 lb TF/TAP with an average of 37.69. Three primary outlet tests ranged from 0.010 to 0.016 lb TF/TAP with an average of 0.01. Three secondary inlet tests ranged from 2.67 to 3.41 lb TF/TAP with an average of 3.02. Three secondary outlet tests ranged from 0.64 to 1.07 lb TF/TAP with an average of 0.81.

Test A_2 data for fluorides show three primary outlet tests ranged from 0.006 to 0.027 lb TF/TAP with an average of 0.016. Three secondary outlet tests ranged from 1.42 to 2.93 lb TF/TAP with an average of 2.05. No inlet fluoride tests were made during test A_2. Test A_2 was conducted for a 24-hour sampling period wherever possible. Test number 3 had to be terminated after 16 hours due to a malfunction discovered in the control device.

A_2 efficiencies were calculated using the inlet data from test A_1. Although A_1 and A_2 primary data correlate closely, the secondary outlet data show a wide range between the two tests and efficiencies. The high primary efficiency on this plant compares closely with a similar system on another plant (E).

Some experimental tests were conducted at Plant B using different filters in the sampling train. Three primary inlet tests for particulates using glass filters ranged from 105.3 to 115.3 lb P/TAP with an average of 111.0. Three tests using paper filters ranged from 86.6 to 131.7 lb P/TAP with an average of 109.4. The overall average of 110.2 lb P/TAP shown on Table 7.5 is for the six tests.

Three primary outlet tests each were conducted for particulates using a glass, paper, and membrane filter. The three tests for the glass filter ranged from 10.60 to 17.30 lb P/TAP with an average of 15.81. Three tests using the paper filter ranged from 10.86 to 21.20 lb P/TAP with an average of 16.20. Three tests using the membrane filter ranged from 6.72 to 12.50 lb P/TAP with an average of 9.91. The average for the nine tests was 13.79 lb P/TAP. No organic extractions were run on these samples. Fluoride tests conducted at this plant were not reported due to questionable analytical procedures.

Tests B_1 show three primary inlet tests for particulates ranged from 97.4 to 101.0 lb P/TAP with an average of 100.3. Inlet particulate tests for test B and B_1 compare favorably. Three primary outlet tests ranged from 1.32 to 2.54 lb P/TAP with an average of 1.80. A comparison of the primary outlet tests between B and B_1 show a wide variance. However, no explanation can be determined for the higher results of B. No secondary particulate tests were taken at this plant.

Test B_1 data for fluorides show three primary inlet tests ranged from 17.4 to 51.7 lb TF/TAP with an average of 37.80. The figure 17.4 lb TF/TAP is suspect as it does not compare to EPA or company data. However, the number was used in calculating the average and efficiency but the data in parenthesis in Table 7.5 show the average and efficiency calculated with the 17.4 figure deleted. Four primary outlet efficiency calculated with the 17.4 figure deleted. Four primary outlet tests ranged from 0.06 to 0.27 lb TF/TAP with an average of 0.14. Four tests of secondary or roof emissions ranged from 1.10 to 1.37 lb TF/TAP with an average of 1.20. The secondary emissions are not controlled but are the emissions that escape the pot hooding in the potroom building.

Plant C data show three primary inlet tests for fluoride ranged from 26.90 to 29.5 lb TF/TAP with an average of 28.10. Three primary outlet tests ranged from 8.42 to 157.30 lb TF/TAP with an average of 69.64. Considerable dirty water droplets were being discharged from the outlet stacks of this plant's primary control system. It was reasonable to expect that some of these droplets were picked up in the sample train during the course of sampling and most, if not all, data from this plant is suspect. Three secondary inlet tests ranged from 8.55 to 9.53 lb TF/TAP with an average of 9.06. Three secondary outlet tests ranged from 7.02 to 7.45 lb TF/TAP with an average of 30. No particulate tests were taken at this plant.

Plant D data for three primary inlet tests for particulates ranged from 63.83 to 83.23 lb P/TAP with an average of 72.26. Three primary outlet tests using a glass filter ranged from 2.16 to 2.30 lb P/TAP with an average of 2.22. No secondary particulate tests were taken at this plant.

Plant D data for three primary inlet tests for fluorides ranged from 56.20 to 64.80 lb TF/TAP with an average of 61.40. Six primary outlet tests ranged from 0.32 to 1.66 lb TF/TAP with an average of 0.87. However, two tests conducted in one day were found to have much higher results (1.60 and 1.66) compared to the other four tests (0.32 to 0.61). It was determined that the control device was malfunctioning during the two runs and the data are suspect. Therefore, the averages were calculated from the primary emission control system using all test data; for comparison, the data deleting the two high tests are shown in parenthesis. Two secondary or roof emission tests ranged from 0.86 to 1.48 lb TF/TAP with an average of 1.17. The roof emissions were not controlled but were emissions escaping the pot hooding in the potroom building.

Three experimental primary outlet tests for fluorides (designated D_1) ranged from 0.38 to 0.50 lb TF/TAP with an average of 0.44. These tests were conducted using the EPA impinger train and heated filter but using a coated stainless steel probe and flexible tubing between the stack and impinger train. The difference between tests D and D_1 was only the sampling train modification. Three other experimental primary outlet tests for fluoride ranged from 0.20 to 0.36 lb TF/TAP with an average of 0.27. These tests were conducted using the same sampling train as above except that sampling was conducted at a single point at the point of average gas velocity through the stack. The average for the six tests is shown in Table 7.5.

Plant E data for three primary inlet tests for fluorides ranged from 35.00 to 54.20 lb TF/TAP with an average of 46.53. Three primary outlet tests ranged from 0.38 to 0.42 lb TF/TAP with an average of 0.41. Four secondary or roof emission tests ranged from 1.10 to 2.85 lb TF/TAP with an average of 2.06. The wide variation in the roof emissions was due the duration of the sampling period, potroom activity during the sampling period, and sampling at a single point in the monitor. For example, test number one was conducted over a 16 hour period and the potroom activity was at a minimum. Test number four was conducted for eight hours and potroom activity under the single sampling point was high.

Plant E data for three primary inlet tests for particulates ranged from 74.5 to 90.8 lb P/TAP with an average of 81.80. Three primary outlet tests ranged from 3.21 to 8.91 lb P/TAP with an average of 5.95. No secondary particulate tests were taken.

Plant F data for three primary inlet tests for particulates ranged from 32.35 to 39.35 lb P/TAP with an average of 38.20. Three primary outlet tests ranged from 1.08 to 1.35 lb P/TAP with an average of 1.34. The fluoride data from this plant were taken by a contractor who analyzed the samples for "gaseous fluorides" and used midget impingers for the sampling train. Therefore, the fluoride data were suspect because they did not agree with any company or EPA data.

Plant G and H are anode bake plant furnace emission data. Plant G data for three outlet tests for particulates ranged from 1.40 to 1.74 lb P/TAnP with an average of 1.56. Three outlet tests for fluorides ranged from 0.70 to 0.98 lb TF/TAnP with an average of 0.88. No inlet emission data were taken.

Plant G data for three outlet tests for fluorides ranged from 1.20 to 1.28 lb TF/TAnP with an average of 1.25. One outlet test for particulates was 3.96 lb P/TAnP. No inlet emission data were taken and time (due to poor weather conditions) prevented any more outlet particulate tests to be run.

Sulfur oxide data ranged from 5 PPM for a prebake plant to 80 PPM for a vertical stud Soderberg plant. No sulfur oxide data were obtained on a horizontal stud Soderberg plant.

Nitrogen oxide emissions averaged less than 5 PPM for all plants.

Efficiencies were calculated for the various plants based on the inlet and outlet loadings on the control system. Only one set of inlet data was taken in most cases. If those data were within the range of values determined by the company, the original inlet data were used to determine efficiencies based on outlet data not taken on the same tests. For example, the fluoride inlet data determined for test A_1 were used to calculate fluoride efficiencies for test A_2. This is also true for tests D and D_1.

7.5.3 Summary

Primary efficiencies for particulate average 95 percent with a range of 85.76 to 99.86 percent. Lack of secondary particulate data precludes any overall efficiency control for particulates in the primary aluminum industry.

Primary efficiencies for total fluoride average 99.42 percent with the range 96.91 to 99.98 percent. However, the 96.91 percent efficient system is no longer in operation. Secondary emission control ranged from 0 percent to 78 percent, but more meaningful efficiency data is shown by the overall control of fluorides. The overall control efficiency for fluoride averaged 96.85 percent with the range from 94.95 to 98.56 percent after deleting Plant A data.

References - Section 7

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8.0 Systems Analysis of Pollution Abatement by Models

The total emissions from an aluminum smelter installation includes controlled or uncontrolled effluents from three groups of process operations, electrode preparation, potline reduction, and cast house operations. The character and quantity of emissions from these three sources differ considerably. Emissions from electrode preparation are largely carbon dusts, with some hydrocarbon volatiles generated in carbon paste materials processing, as well as combustion gases, smoke and volatiles resulting from anode baking. Potline emissions include particulates and gases arising directly from the production of the molten metal. Cast house emissions are combustion gases and fumes, primarily aluminum chloride which may hydrolyze in the presence of atmospheric moisture to HCl and Al_2O_3.

Insufficient quantitative and qualitative data are available from reporting or published sources concerning carbon plant or cast house emissions to provide the basis for systems analysis of their generation and control. Their quantities are orders of magnitude less than those from potline operations; emission control is exercised on most effluent streams, but not measured.

Some scanty data are available on bake plant emissions, but are not adequate for purposes of a meaningful systems analysis on an industry basis.

A systems analysis approach applied to models representing current aluminum industry reduction practices provides insight into the potential effectiveness of pollution control equipment used in various combinations. For this analysis typical effluent parameters have been established from industry data as the basis of models defining types of operation in the industry. The performance and costs of alternative pollution control equipment combinations have been evaluated as they apply to the effluent models.

These evaluations indicate the degrees of overall control efficiency which should be attainable within limits of capital investment and annual operating costs.

Descriptions of removal equipment and derivations of their assumed removal efficiencies for solid and gaseous fluoride are given in other parts of this report. In this section applications of control schemes applied to industry effluent models are described. The components of capital and operating costs for each control scheme are combined and compared with performance parameters to give a measure of cost effectiveness for the control model and to provide the basis for estimating costs involved in upgrading the overall pollution control of the primary aluminum industry.

8.1 Models of Potline Effluent Controls

Most of the attention to air pollutant control in the primary aluminum industry has been directed toward fluoride effluents from the alumina reduction potlines. Although some objectionable pollutants derive from anode baking operations and other process activities at a smelter, it is the large quantities of gaseous and solid fluorides emanating from the cryolite bath of the potlines which present the most serious hazard to plant and animal life and which have received the major portion of technical effort to control.

The control of emission opacity, as judged by Ringlemann standards, is complicated by the presence of submicron hydrocarbon aerosols in effluents from anode bake plants and Soderberg anode potlines. Plume opacity problems may be more severe in plants which combine and discharge emissions from a central system through a single stack. The same emissions from a number of separate points might individually meet the Ringleman standard adopted. Some of the control schemes considered herein among the models, while effective for the abatement of particulate and gaseous fluoride air pollution, might not satisfy the additional requirement of controlling submicron hydrocarbon aerosols which contribute most to plume opacity in central stack emissions.

8.1.1 Model Structure

To assess the performances of various emission control schemes applied to similar effluent situations in the primary aluminum industry, a number of plant effluent models have been established. These models represent various combinations of effluents and effluent collection systems which are applicable to the three major kinds of reduction cell installations, viz., prebake anodes, HSS Soderberg anodes and VSS Soderberg anodes. To these streams can be applied various combinations of emission control devices, or control schemes. Such a control model structure is shown diagrammatically in Figure 8.1.

Primary stream collection is defined as the direct removal of cell effluent through hoods on individual pots, ducted to a common emission control system serving a group of pots.

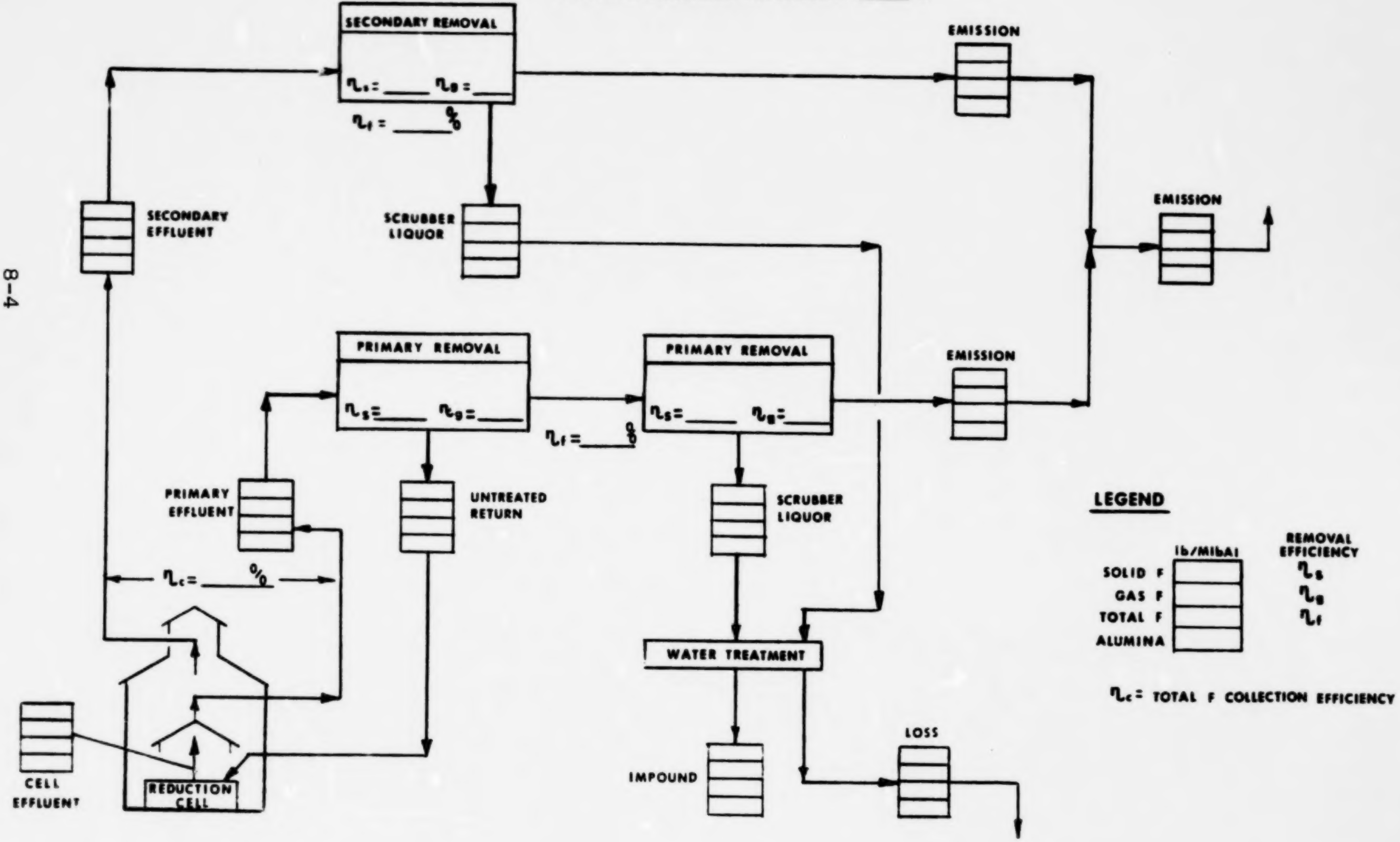
Secondary stream collection is defined as the gathering of potroom effluents, including those not collected by primary hooding, together with potroom ventilation airflow, by using the potroom structure as a containment envelope and exhausting through one or more roof plenums.

Although a part of the particulate material passing through the roof monitor secondary system originates from mechanical operations within the potroom and not from cell operations per se, collection or hooding efficiencies and model effluent quantities are considered on the basis that all particulates as well as gaseous fluorides are assumed to originate at the cell surface. Estimates of pollutant removal performance and equipment costs are not influenced by this simplification in the model.

Collection efficiencies are expressed as the percentage of the total effluent collected into a primary stream, in terms of total fluorides, calculated from components of solid fluorides and gaseous fluorides.

Cognizance is taken in the control model structure of the potential of returning collected dry fluorine bearing products to the reduction cell without reprocessing. This potential is assumed to exist only with

FIGURE 8.1
SCHEMATIC FLOW DIAGRAM
ALUMINUM SMELTER AIR POLLUTION CONTROL
SYSTEM MODEL:
OVERALL CONTROL EFFICIENCY:_____%


SECONDARY REMOVAL
η_s = ____ η_g = ____
η_f = ____%
EMISSION
EMISSION
SECONDARY EFFLUENT
SCRUBBER LIQUOR
PRIMARY REMOVAL
η_s = ____ η_g = ____
PRIMARY REMOVAL
η_s = ____ η_g = ____
η_f = ____%
EMISSION
PRIMARY EFFLUENT
UNTREATED RETURN
SCRUBBER LIQUOR
η_c = ____%
WATER TREATMENT
CELL EFFLUENT
REDUCTION CELL
IMPOUND
LOSS
LEGEND
lb/MlbAl
REMOVAL EFFICIENCY
SOLID F η_s
GAS F η_g
TOTAL F η_f
ALUMINA
η_c = TOTAL F COLLECTION EFFICIENCY

control equipment applied to the primary stream.

The following effluent models have been selected to represent the various types of primary aluminum reduction plants.

	Type of Cell	Collection Arrangement Primary	 Secondary
IA	Prebake Anode	Controlled	Uncontrolled
IB	Prebake Anode	Controlled	Controlled
IC	Prebake Anode	None	Controlled
ID	Prebake Anode	None	Uncontrolled
IIA	VSS Soderberg	Controlled	Uncontrolled
IIB	VSS Soderberg	Controlled	Controlled
IIIA	HSS Soderberg	Controlled	Uncontrolled
IIIB	HSS Soderberg	Controlled	Controlled

Primary collection is always used with Soderberg cells and thus no model corresponding to IC is applicable to Soderberg cell plants.

The control schemes applied to the models have been selected to suit the physical characteristics of the model effluent streams. Removal efficiencies of control schemes are defined as the percentage removal of the component (solid fluoride or gaseous fluoride) from the feed stream to the control device. Removal efficiencies are considered to be independent of equipment size or capacity.

Most removal efficiencies for solid F are derived from test data on actual potline effluents. (Ref. Table 5.2) Where no data exist, efficiencies were estimated from fractional efficiency curves and the assumption that solid F particle size distributions are similar to those for total solids evolving from potline operation. The validity of this assumption is questioned by some investigators.

8.1.2 Model Parameters

Effluents

The quantities and characteristics of effluents entering the several control systems described by the above models are determined partly by the type of reduction cell and partly by the efficiency with which primary collections systems separate the effluents into primary and secondary component streams.

All three types of reduction cell, so far as can be determined, generate the same total quantities of total fluorides in their effluents amounting to an average of 23 pounds per 1000 pounds of aluminum produced.

In the prebake and HSS Soderberg cell effluents there are approximately equal amounts of solid and gaseous fluorides in which a large part of the particulate fluoride is submicron in diameter.

In the VSS Soderberg, after the burner, the collected effluent contains approximately 90 percent of the total fluorine as HF, and has a low particulate fluoride content, resulting probably from a greater increased opportunity for hydrolyzation by contact of the fume with moist air from combustion of hydrocarbons after passing through the burner. 8.1/

Primary Collection Efficiency

The efficiency of primary collection at the reduction cell depends on the mechanical design of the hoods, which is governed by the type and configuration of the cell, the extent to which the hooding devices are kept intact and in good repair, and the amount of interference by cell operations with the hooding effectiveness.

A high collection efficiency for both gases and solids can be obtained with modern prebake cells in which the hood design is integral with cell construction, and in which feeding and crust breaking operations can be carried out at the center between rows of anodes with minimum disruption of the hooding protection. Side-worked prebake cells, on which hooding has been added after original design, characteristically show lower collection efficiency. The terms "new" and "old" are used in model analyses to designate this difference.

Primary collection efficiency for side-worked Soderberg cells is lower than for the newer center-worked prebake cells. In the VSS Soderberg, there is a substantial area of cell surface outside the skirt through which cell working is accomplished with consequent evolution of uncollected pollutant. In the HSS Soderberg, the hooding enclosure must be breached partially to work the cell or entirely to pull the anode channels for stud relocation.

The collection efficiency with respect to particulates in an effluent stream appears to be somewhat less than that of gaseous collection, and the order of magnitude of this differential has been estimated from data reported in the industry responses to the questionnaires. Part of this apparent difference in collection efficiency may be attributable to the fact that pot working operations account for a large part of solids effluent and it is characteristic of many pot working conditions that part of the hooding may be removed at the time. Also, since fluoride dust released to the potroom from sources other than the cell itself is counted as cell effluent escaping the hooding, this unmeasured quantity reduces the apparent collection efficiency.

Controlled Effluent Streams

The quantitative parameters adopted for the effluents referenced to the models are summarized in Table 8.1.

To be valid, the model parameters must approximate those of the corresponding plant installations in the industry. They have, therefore, been chosen after evaluation of industry reported data, which are not entirely consistent within themselves. However, it has been possible, by a technique of weighted averages, to arrive at parameters which can be taken to be illustrative of industry conditions and practice within reasonable limits.

Table 8.1

MODEL EFFLUENTS ENTERING CONTROL SYSTEMS

Basis: 1000 lb Aluminum

Component	I New* PB			I Old* PB			II VSS			III HSS		
	Tot.	Prim.	Sec.	Tot.	Prim.	Sec.	Tot.	Prim.	Sec.	Tot.	Prim.	Sec.
Solid F, lb	10	9.5	0.5	10	8.0	2.0	3	1.5	1.5	10	8.0	2.0
HF, lb	13	12.6	0.4	13	11.7	1.3	20	17.0	3.0	13	11.7	1.3
Total F, lb	23	22.1	0.9	23	19.7	3.3	23	18.5	4.5	23	19.7	3.3
Alumina, lb	20	19.0	1.0	20	16.0	4.0	3	1.5	1.5	20	16.0	4.0
Total Solids, lb	48	46.1	1.9	48	41.3	6.7	39	25.9	13.1	49	38.2	10.8
Air, 10^6 ACF	27.5	2.5	25	27.5	2.5	25	35.5	0.5	35	38.5	3.5	35
Collection, Eff.												
Solid F		95			80			50			80	
HF		97			90			85			90	
Total F		96.0			85.6			80.4			85.6	

*Refers to average collection efficiencies between those of "new" potlines and those to which hooding may have been added after original design.

Collection Systems

Primary effluent collection systems comprise the hooding devices installed at the reduction cells (including the skirts and burners on VSS Soderberg cells), the individual cell ducting to common headers serving groups of cells, and the main ducting leading to control devices. Practice varies among aluminum smelters as to the number of cells connected with a single control system. In centralized systems, an entire potline of 150 or more cells may be ducted to a single control system, whereas the decentralized systems, where smaller control units are usually located in courtyards between potlines, may connect 20 or fewer cells to each control system. Figures 8.2 illustrate schematically several possible collection system configurations for PB, VSS and HSS potlines. The illustrated courtyard schemes are patterned after existing installations and were selected as the bases for control system models.

Costs for a central scheme usually are greater than for courtyard schemes as will be shown in Section 8.2.1. These cost differences may be offset by differences in the total costs of very large units of removal equipment for central systems compared with smaller units for courtyard systems.

Considerations other than costs, such as flexibility by provision of duct interconnections for continued pollution control when part of a system may be out of service, and the ease of cleaning deposits from the inside of ducting, may influence the design of collection systems. Maximum collection efficiencies are realized when the system designs provide for continuous exhausting of all operating cells through removal equipment even when parts of a potline are being serviced, and when provisions are made in the collection system to increase air flow rate from a cell which may have part of its hooding removed for cell working or anode replacement.

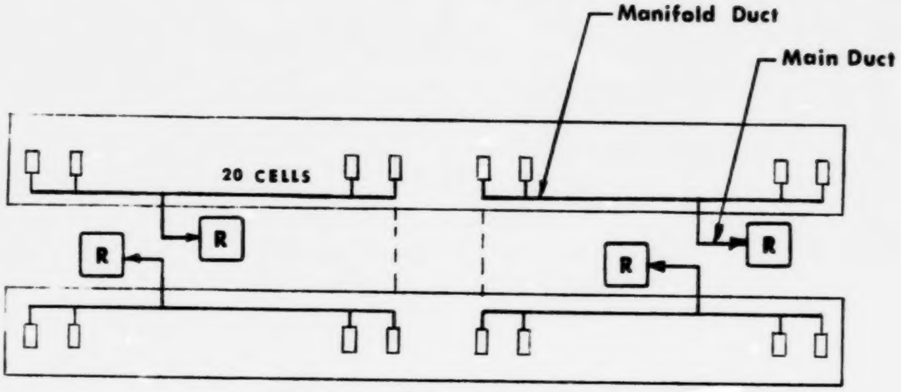
8.1.3 Overall Emission Control

The overall emission control, measured by either the overall control efficiency (OCE) or by the weight of the emitted total fluorides per 1000 pounds of aluminum produced, is a function of three independent variables,

FIGURE 8.2a

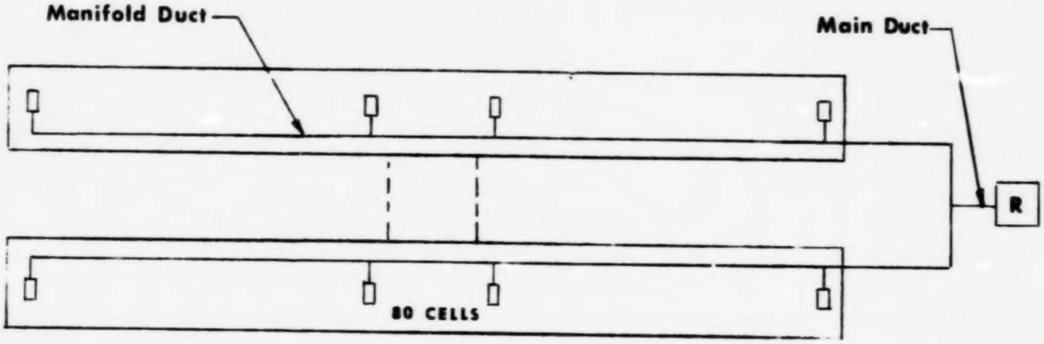
PRIMARY COLLECTION SYSTEMS

Typical ducting layouts for a Single Prebake Potline – 160 cells, two rooms.


Manifold Duct
Main Duct
20 CELLS
R
R
R
R

COURTYARD SCHEME

[20 cells per manifold duct]


Manifold Duct
Main Duct
R
80 CELLS

CENTRAL SCHEME

[80 cells per manifold duct]

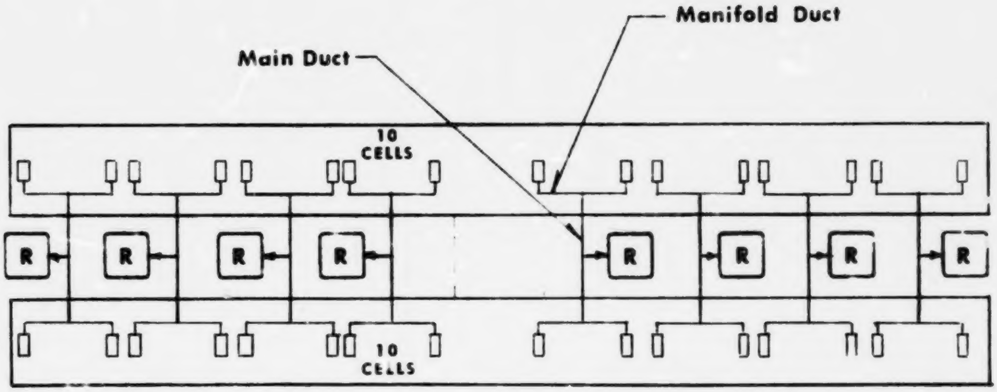
Symbol

R Removal Equipment

FIGURE 8.2b

PRIMARY COLLECTION SYSTEMS

Typical ducting layout for a Single VSS Potline - 160 cells, two rooms.


Manifold Duct
Main Duct
10 CELLS
R
R
R
R
R
R
R
R
10 CELLS

COURTYARD SCHEME

[10 cells per manifold-main ducting]

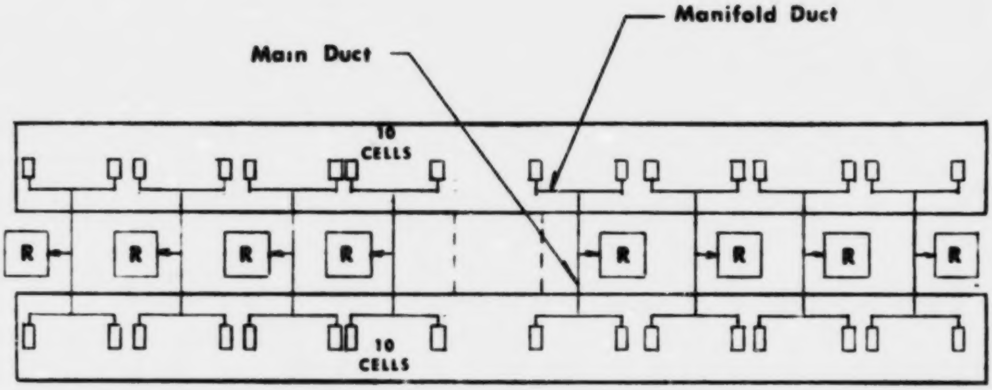
Symbol

R **Removal Equipment**

FIGURE 8.2c

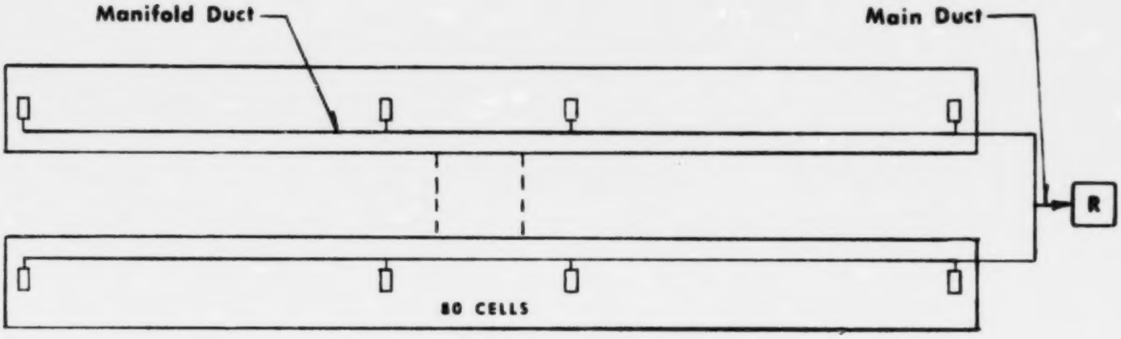
PRIMARY COLLECTION SYSTEMS

Typical ducting layout for a Single HSS Potline – 160 cells, two rooms.


Manifold Duct
Main Duct
10 CELLS
R
10 CELLS

COURTYARD SCHEME

[10 cells per manifold duct]


Manifold Duct
Main Duct
R
80 CELLS

CENTRAL SCHEME

[80 cells per manifold duct]

Symbol:

R Removal Equipment

primary collection efficiency (η_c), removal efficiency of devices used to treat the primary collected stream (η_p), and the removal efficiency of secondary stream control devices (η_s). The relationship among these may be expressed as,

$$OCE = \eta_c \eta_p + (1-\eta_c) \eta_s$$

The determinant factors in obtaining high overall control efficiencies are, in order of impact,

1. Primary removal efficiency
2. Primary collection efficiency
3. Secondary removal efficiency

For example, the best demonstrated combination of available technology for collection and primary removal alone in a prebaked potline (96 and 98.6 percent respectively) results in an overall control efficiency of 94.6 percent, corresponding to about 1.2 pounds total fluoride emission per 1000 pounds aluminum produced.

Addition of secondary treatment to the primary control system results in small, but significant, increments to overall control efficiency. A 63.6 percent efficient secondary system added to the best available primary system raises overall control efficiency to 97.1 percent (0.67 pound total fluoride emission per 1000 pounds aluminum).

It is apparent that to reach a control level with prebake cells of say 96 percent (about 0.92 pound fluoride emission per 1000 pounds of aluminum produced) a secondary system of at least 33 percent removal efficiency would be needed in combination with the best available primary collection and removal techniques, and that if the secondary efficiency were greater, the combination of optimum primary parameters could be somewhat relaxed.

The above line of reasoning can be applied to the situations of Soderberg potlines. However, the nature of the design of both VSS and HSS Soderberg cells make it virtually impossible to achieve collection efficiencies as high as for modern prebake potlines.

For situations where no primary collection is used, and all emission control is exercised on the secondary stream, overall emission control is limited to the secondary removal efficiency. Low pollutant loadings in the air streams with correspondingly low removal driving force and inordinately high costs for high performance removal equipment, as referenced in Tables 8.4, make high levels of overall control efficiency impractical.

8.1.4 Control Schemes Applied to Models

From among the various control devices and combinations applicable to the removal of reduction plant pollutants, a selection has been made for control schemes to be applied to the potline effluent models, including those control schemes which are in current plant use as well as others which represent the higher ranges of technically achievable performance with effluents characteristic of the models.

In practice, the actual values of the effluent conditions in individual plants will not correspond exactly to the average parameters assumed for the models as shown in Table 8.1. The overall emission control plant performances obtained with similar removal equipment will, therefore, vary to some extent from those derived from the model control schemes which are representative of the industry groupings.

Tables 8.2 list, by models and model control schemes, the control scheme removal efficiencies and the overall control efficiencies corresponding to the collection efficiencies and flow rates postulated for the various models.

Appendix 8A presents the simplified flow diagrams and calculated emission data for some of the model control schemes listed in Tables 8.2.

Table 8.2a

MODEL CONTROL SCHEMES AND EFFICIENCIES

PREBAKE POTLINES - MODEL I

Model Number	Equipment* Designator	Equipment Removal Eff.			Overall Control Eff. Total F Collection Eff.	
		Solid F	HF	Total F	96.0	85.6
IA - Prebake Primary						
-1	FBDS	98	99	98.6	94.6	84.4
-2	MC+VS	96	99	97.7	93.8	83.6
-3	MC+HPSS-3	93	98	95.9	92.1	82.1
-4	DESP+ST	98	95	96.2	92.4	82.3
-5	MC+CFPB-5	87	98	93.4	89.6	80.0
-6	MC+ST	80	95	88.8	85.2	76.0
-10	CFDS	98	90	93.4	89.6	80.0
-11	MC	78	-	33.6	32.2	26.7
-12	ST	80	95	88.7	85.2	75.9
-13	MC+DESP+ST	90	95	93.0	89.2	79.6
-14	MC+VPB-3	85	66	74.8	71.8	64.0
-15	MC+FBWS	80	98	90.8	87.2	77.2
-16	CS	85	88	86.4	83.0	74.0
-17	IADS	98	98	98	94.1	84.0
IB - Secondary (with Primary)						
-9	SS	25	80	-	1.9**	6.7**
IC - Secondary Only (no Primary)					All Effluent to Sec.	
-7	CFPB-3	84	99	92.5	92.5	
-8	FBWS	75	93	85.2	85.2	
-9	SS	45	93	72.1	72.1	

* Underlined equipment designators signify equipment in current use on prebake potlines. Legend follows Table 8.2c.

** Overall control efficiency values for Model IB are to be added to values for Model IA to evaluate performances of combined control schemes.

NR = Not reportable.

Table 8.2b

MODEL CONTROL SCHEMES AND EFFICIENCIES

VSS SODERBERG POTLINES - MODEL II

Model Number	Equipment* Designator	Equipment Removal Eff.			Overall Control Eff. Total F Collection Eff. $\eta_c = 80.4$
		Solid F	HF	Total F	
IIA - VSS Primary					
-1	ST+WESP	99	99	99.0	79.6
-2	FBDS	98	99	98.9	79.5
-3	DESP+ST	98	99	98.9	79.5
-4	MC+VS	96	99	98.8	79.4
-5	MC+HPSS-3	93	98	97.6	78.4
-6	MC+CFPB-5	87	98	97.1	78.0
-8	ST	75	99	93.0	74.6
-9	IADS	98	98	98.0	78.7
IIB - VSS Secondary (with Primary)					
-7	SS	42	88	72.7	14.2**

* Underlined equipment designators signify equipment in current use on VSS Soderberg potlines. Legend follows Table 8.2c.

** Overall control efficiency values for Model IIB are to be added to values for Model IIA to evaluate performances of combined control schemes.

Table 8.2c

MODEL CONTROL SCHEMES AND EFFICIENCIES

HSS SODERBERG POTLINES - MODEL III

Model Number	Equipment* Designator	Equipment Removal Eff.			Overall Control Eff. Total F Collection Eff. $\eta_c = 85.6$
		Solid F	HF	Total F	
IIIA - HSS Primary					
-1	CFPB-5+WESP	98	98	98	83.9
-2	ST+WESP	98	93	95	81.3
-3	CFPB-5	81	98	91.1	78.0
-4	ST	64	93	82	70.2
-5	FBWS	78	98	89.9	76.9
IIIB - HSS Secondary (with Primary)					
-6	SS	25	80	45	6.5**

* Underlined equipment designators signify equipment in current use on HSS Soderberg potlines. Legend follows.

** Overall control efficiency values for Model IIIB are to be added to values for Model IIIA to evaluate performances of combined schemes.

Legend for Tables 8.2a, b and c

CFPB-5	Cross Flow Packed Bed Scrubber (5 ft. Deep)
CFPB-3	Cross Flow Packed Bed Scrubber (3.25 ft. Deep)
CS	Chamber Scrubber
DESP	Dry Electrostatic Precipitator
FBDS	Fluidized Bed Dry Scrubber
FBWS	Floating Bed (Bouncing Ball) Wet Scrubber
HPSS-3	High Pressure Spray Screen (3-Stage)
IADS	Injected Alumina Dry Scrubber
MC	Multiple Cyclone
SS	Spray Screen
ST	Spray Tower
VPB-3	Vertical Flow Packed Bed Scrubber (3ft. Deep)
VS	Venturi Scrubber
WESP	Wet Electrostatic Precipitator

8.2 Costs (Based on 1970 Dollars)

Cost effectiveness analyses for control schemes applied to model potlines are based on both capital investment and annual costs. The following paragraphs outline the elements of these costs assuming new plant installations. Modifications to existing plants involve additional costs which may vary widely according to specific circumstances.

8.2.1 Capital Costs - Model Control Schemes

The capital costs of the model control schemes are the sums of the capital costs of the elements, including collection systems, pollutant removal equipment stages for primary and secondary effluent treatment, and costs of scrubber water treatment for removal.

The capital costs of each element are expressed in dollars per annual capacity ton of aluminum and are made up (a) equipment purchase costs plus (b) direct installation costs plus (c) indirect installation costs.

Purchase costs were estimated from cost curves developed from manufacturers information and, in some cases, from actual costs reported by respondent plants. The cost curves are presented in Appendix 8B as functions of air flow-rate capacity.

Primary removal equipment capacities were based on the use of collection systems corresponding to courtyard arrangements (40 cell groups for prebake, 20 cell groups for Soderberg). Equipment unit capacities assumed were 100,000 cfm dry air for prebake collection systems, 10,000 cfm dry air for VSS applications and 60,000 cfm moist air for HSS Systems. An arbitrary 10 million cfm of secondary systems air per grouping of control units was chosen as the basis for costing the equipment in secondary removal systems.

Direct installation costs, which include costs for transportation of equipment, site preparation, foundations, erection, utility connections and auxiliaries such as fans, inlet ductwork, motors and control instrumentation, were calculated by applying the factors shown in the following table to the control equipment purchase cost. 8.2/

Equipment Type	Installation Cost, Percent
Dry Centrifugal	70
Wet Collectors	
Venturi	200
All Others	100
Electrostatic Precipitators	
Dry (plate type)	70
Wet (plate type)	75
Fabric Filters	75

Indirect installation costs were estimated as a percentage addition to direct installed costs, and were made up of:

Engineering	7%
Construction Overhead	1%
Start-up Expense	3%
Initial Spares	2%
Sales Taxes	2% 1/
Contingencies	15%
Total	30%

1/ This figure is representative; sales tax rates vary from state to state and in addition many states exempt air pollution control facilities from sales and use taxation.

Scrubber water treatment costs were added as an element of total removal scheme costs where the removal scheme includes the solution of HF in water.

Although some existing smelters discharge scrubber water to moving bodies of water without fluoride removal treatment, increasing awareness of the need to protect the total environment makes it likely that any new installation would be required to remove most fluoride from scrubber water prior to release from the plant. Normally this is accomplished by precipitating dissolved fluoride as calcium fluoride by reaction with lime, with subsequent separation of the precipitate and accompanying removed particulates in a clarifier for impounding. The capital cost for this process equipment is estimated to be $130 per gpm of water flow required by the scrubber equipment used.

There are special situations where scrubber liquor may be economically treated with sodium aluminate and caustic soda to recover dissolved fluoride as cryolite. A smelter located adjacent to a Bayer process alumina-from-bauxite plant may have a convenient and low cost source of sodium aluminate solution, the Bayer process green liquor, which may be reacted with dissolved fluoride in scrubber liquor to produce low grade cryolite (approximately 45 percent cryolite, 55 percent alumina). Alternatively, high grade cryolite plants, which use spent pot lining as primary source of fluoride, recover additional fluoride from scrubber liquor. Except as these special circumstances obtain, fluoride recovery from scrubber liquor appears uneconomical.

Collection systems costs were estimated for both courtyard and central systems, using the configurations shown in Figures 8.2, model effluent flow-rates given in Table 8.1, and the assumption that the cells produce one pound of aluminum per minute. A summary of these estimates is presented in Table 8.3.

Most United States plants have employed the courtyard collection system and this pattern has been followed in the structuring of the control schemes.

Table 8.3

ESTIMATED CAPITAL COSTS OF PRIMARY COLLECTION SYSTEMS
($ Per Ton Aluminum at Full Plant Capacity)
(New Construction)

Collection System Configuration	Prebake Cells		VSS Soderberg		HSS Soderberg	
	Courtyard	Central	Courtyard	Central	Courtyard	Central
Cell Hood (or Skirt and Burner) and Branch Duct	$ 6.18	$ 6.18	$ 5.71	Not	$ 6.18	$ 5.71
Manifold Duct	10.89	24.96		Used	17.92	34.40
Main Duct	5.62	2.54	13.40		9.92	2.62
Total	$22.69	$33.68	$19.11		$34.02	$42.73
Basis:						
Annual Production Per Cell, Tons	262.8		262.8		262.8	
Cell Current, Amps	90,000		90,000		90,000	
Air Flow per Cell acfm	2,500		500		3,500	

Source - Estimates by Singmaster & Breyer

Secondary control systems, which treat all building ventilation air, have been assumed to have no collection system costs which would not be incurred for building ventilation without control. Therefore the model analyses of Section 9 have no added costs for secondary collection.

8.2.2 Annualized Costs

Annualized costs for the control of potline effluents on the basis of dollars per ton of aluminum produced at plant capacity are taken as the sum of direct operating costs 1/, various indirect costs 2/, and an annualized cost of invested capital 3/. Pollution control schemes which recover fluoride and alumina values earn corresponding credits which are applied to the total annualized cost to obtain net annualized costs. The elements of estimated costs are tabulated for each of the several model control scheme components in Tables 8.4, pages 8-27, 8-28, 8-29, and are detailed following.

Operating labor and materials charges against collection and removal equipment were analyzed on the basis of limited data on manpower to perform various routine tasks and on the basis of responses to the industry questionnaire.

A weighted average of industry reported operating labor and material costs amounted to $0.40 per ton of aluminum produced. Using an average labor rate of $5.35 per manhour including 23 percent fringe benefits, $0.40 per ton is approximately equivalent to one man full time per 2½ potlines. Expressed another way, this is approximately equivalent to 0.08 manhour per ton of aluminum. For the purpose of allocating labor charges to each component of control equipment, the following breakdown was assumed.

1/ Operating labor and materials, electric power, water, chemicals, maintenance labor and materials.

2/ Royalty, other operating costs including taxes, insurance and depreciation.

3/ Equivalent to interest at 8 percent on a continuing debt equal to the capital cost.

	Manhour/Ton
Straightening and changing collection hood shields	0.015
Unloading dry removal equipment	0.006
Sump cleaning, nozzle and pipe changing for wet scrubber systems	0.034
Monitoring total systems	0.025
Total	0.080

Electric power requirement was calculated from manufacturers information on the equipment, and was priced at 6 mills per kilowatt hour.

Water was assumed to be consumed at a rate of 3 percent of the circulation rate required for the equipment in question and was assumed to cost $0.013 per 1000 gallons.

Chemicals for the neutralization of acid scrubbing water from primary scrubber units were calculated to cost $0.54 ± 0.02 per ton of aluminum produced, depending on the removal efficiency for HF and based on a price of $18.00 per ton of lime (90 percent CaO).

Maintenance labor and material is estimated to cost 5 percent of the total capital cost per year.

Royalty costs are associated with the dry scrubbing of effluent gas by ore grade alumina with the resultant adsorption of the fluorine on the alumina.

A cost evaluation of the presently reported licensing terms has been made by assuming an annual interest payment for an indefinite period for a debt that covers the fees and royalty payments, the debt interest rate being 8 percent.

Other operating costs include the following components:

Depreciation	8%	of	total	capital	costs
Administration	5%	"	"	"	"
Property taxes and insurance	2%	"	"	"	"
Total	15%	"	"	"	"

The figure used for property taxes and insurance is representative for locations in which present aluminum reduction plants are located, considering that the classes of property taxes vary from state to state, and that some states exempt air pollution control facilities from property taxation.

Interest at a rate of 8 percent of total capital costs on a debt of indefinite duration is assumed in lieu of capital recovery (interest and amortization) over a finite period of time.

8.2.3 Control Systems Credits and Net Annualized Unit Costs

Cost credits for returned alumina and F values may be earned by some control schemes, such as dry particulate collection and dry gas scrubbers which remove fluorine from the effluent stream in a form which may be recycled to the cells without reprocessing. Alumina is valued at $0.032 per contained pound and fluoride at $0.25 per pound of contained F in dry recycle. Twenty-five cents per pound of contained F corresponds to 90 percent cryolite at $245 per ton or to 90 percent aluminum fluoride at $305 per ton.

Where applicable, control scheme credits are subtracted from total annualized costs for individual equipment components to arrive at a net annualized cost.

An analysis of the material balance concerning the return to the cell of adsorbed HF discloses that each pound of F requires 0.9 pound of alumina to reform the bath constituent, aluminum fluoride. In terms of the effluents assumed to be removed by the dry scrubbing processes as applied to the model prebake potlines in Section 8, nearly two-thirds of the removed alumina is required to react with the removed HF before that fluoride becomes again available to the bath from which it was vaporized. In the cases of removal equipment in which dry scrubbing of HF occurs, the credit for returned alumina has been adjusted downward to account for that which is chemically associated with the returned HF in reforming aluminum fluoride.

A difference of opinion exists among users of dry scrubbing systems within the aluminum industry as to the validity of this analysis. However, the denial of credit to 0.9 pound of alumina per pound of F results in a conservative estimate of financial credit earned by dry scrubbing systems.

8.2.4 Summary of Cost Elements

Tables 8.4 summarize the above cost elements for each major component of the control schemes, including the collection systems, for each of the three types of potline, based on unit capacities of equipment which conform to the requirements of the effluent flows in the collection systems modeled.

Judgment should be exercised in the application of these model element costs to systems defined by other parameters. Variations from individual plant installations in airflow quantity per ton of aluminum produced and differences between actual equipment investment costs and the values developed for the model can have a significant influence on both capital and net annual costs. The model element costs presented here are useful for making comparisons among control schemes, one scheme to another.

TABLE 8.4a

COST ELEMENTS - PREBAKE MODELS

	PRIMARY CONTROL SCHEMES *														SECONDARY CONTROL SCHEMES **			
EQUIPMENT DESIGNATOR		FBDS	VS	HPSS-3	DESP	CFPB-5	ST	MC	CFDS	FBWS	CS	VPD-3	IADS		CFPB-3	FBWS	SS	
Cost Component / Equipment Name	Primary Collection	Fluidized Bed Dry Scrubber	Venturi Scrubber	High Pressure Spray Screen (3-Stage)	Dry Electrostatic Precipitator	Cross Flow Packed Bed (5 ft Deep)	Spray Tower	Multiple Cyclone	Coated Filter Dry Scrubber	Floating Bed Wet Scrubber	Chamber Scrubber	Vertical Packed Bed	Injected Alumina Dry Scrubber	Water Treatment (Lime)	Cross Flow Packed Bed (3.25 ft Deep)	Floating Bed Wet Scrubber	Spray Screen	Water Treatment (Lime)
CAPITAL COST, $/Ann Ton Al																		
Purchase Cost 1/	22.69	28.54	5.71	9.51	7.80	5.52	2.47	1.23	13.30	5.33	4.28	3.33	30.01	3.04	23.78	35.67	14.27	5.76
Direct Installation 2/	↓		11.42	9.51	5.[illegible]	5.52	2.47	0.87	10.00	5.33	4.28	3.33	↓	↓	23.78	35.67	14.27	↓
Indirect Installation 3/		8.56	5.14	5.71	3.[illegible]	3.31	1.49	0.63	7.00	3.19	2.57	2.00	2.40 19/		14.27	21.40	8.56	
TOTAL CAPITAL COST	22.69 4/	37.10 19/	22.27	24.73	17.24	14.35	6.43	2.73	30.30	13.85	11.13	8.66	32.41	3.04	61.83	92.74	37.10	5.76 5/
ANNUALIZED UNIT, $/Ton Al																		
Operating Labor & Mtls	0.08 7/	0.34 6/	0.31 7/	0.31 7/	0.03 7/	0.31 7/	0.31 7/	0.03 7/	0.34 6/	0.31 7/	0.31 7/	0.31 7/	0.50 6/	0.20 7/	0.40 6/	0.40 6/	0.40 6/	0.20 7/
Electric Power 8/	0.35	1.67	3.60	1.90	0.13	0.25	0.25	0.35	1.67	0.41	0.25	0.32	0.67	0.22	2.16	3.51	1.94	0.48
Water 9/	-	-	0.02	0.04	-	0.02	0.02	-	-	0.02	0.02	0.02	-	-	0.25	0.25	0.25	-
Chemicals 10/	-	-	-	-	-	-	-	-	-	-	-	-	-	0.36 10/	-	-	-	0.05 11/
Maint Labor & Mtls 12/	1.13	1.86	1.11	1.24	0.86	0.72	0.32	0.14	1.52	.69	.56	.43	1.62	0.15	3.09	4.64	1.86	0.29
Royalty	-	0.34 13/	-	-	-	-	-	-	-	-	-	-	- 18/	-	-	-	-	-
Other Operating Costs 14/	3.40	5.57	3.34	3.71	2.59	2.15	0.96	0.41	4.55	2.08	1.67	1.30	4.86	0.46	9.27	13.91	5.57	0.86
Subtotal	4.96	9.78	8.38	7.20	3.61	3.45	1.86	0.93	8.08	3.51	2.81	2.38	7.65	1.39	15.17	22.71	10.02	1.88
Interest 15/	1.82	2.97	1.78	1.98	1.38	1.15	0.51	0.22	2.42	1.11	.89	.69	2.59	0.24	4.95	7.42	2.97	0.46
TOTAL ANNUALIZED COST	6.78	12.75	10.16	9.18	4.99	4.60	2.37	1.15	10.50	4.62	3.70	3.07	10.24	1.63	20.12	30.13	12.99	2.34
CREDITS																		
Returned Alumina 16/	-	(0.40)	-	-	(1.07)	-	-	(0.87)	(0.40)	-	-	-	(0.40)	-	-	-	-	-
Returned F Values 17/	-	(10.14)	-	-	(4.17)	-	-	(3.40)	(9.65)	-	-	-	(10.14)	-	-	-	-	-
TOTAL CREDITS	-	(10.54)	-	-	(5.24)	-	-	(4.27)	(10.05)	-	-	-	(10.54)	-	-	-	-	-
NET ANNUALIZED COST	6.78	2.21	10.16	9.18	(0.25)	4.60	2.37	(3.12)	0.45	4.62	3.70	3.07	(0.30)	1.63	20.12	30.13	12.99	2.34

* Control device unit capacities are assumed at 100,000 acfm for dry units and 82,000 acfm for wet units.

** Based on 10 million acfm of equipment capacity.

Footnotes follow Table 8.4c.

TABLE 8.4b

COST ELEMENTS - VSS SODERBERG MODELS

EQUIPMENT DESIGNATOR	PRIMARY CONTROL SCHEMES *												SECONDARY CONTROL **	
		ST	WESP	FBDS	DESP	MC	VS	HPSS-3	CFPB-5	IADS			SS	
Cost Component / Equipment Name	Primary Collection	Spray Tower	Wet Electrostatic Precipitator	Fluidized Bed Dry Scrubber	Dry Electrostatic Precipitator	Multiple Cyclone	Venturi Scrubber	High Pressure Spray Screen (3-Stage)	Cross Flow Packed Bed (5 Ft. Deep)	Injected Alumina Dry Scrubber	Water Treatment (Lime)		Spray Screen	Water Treatment (Lime)
CAPITAL COST, $/Annual Ton Al														
Purchase Cost 1/	19.11 4/	1.52	10.71	8.05 19/	5.71	0.48	3.81	3.01	3.01	10.95 19/	5.39 5/		19.98	8.00 5/
Direct Installation 2/	↓	1.52	8.03	↓	4.00	0.34	7.62	3.01	3.01	↓	↓		19.98	↓
Indirect Installation 3/		0.76	2.41	2.42	2.91	0.25	3.43	1.81	1.81	0.88			11.98	
TOTAL CAPITAL COST	19.11 4/	3.80	21.15	10.47 19/	12.62	1.07	14.86	7.83	7.83	11.83 19/	5.39 5/		51.94	8.00 5/
ANNUALIZED UNIT, $/Ton Al														
Operating Labor & Materials	0.08 7/	0.31 7/	0.03 6/	0.55 19/	0.03 7/	0.03 7/	0.31 7/	0.31 7/	0.31 7/	0.40 6/	0.20 7/		0.40 6/	0.20 7/
Electric Power 8/	0.06	0.15	0.06	0.24 19/	0.04	0.10	0.61	0.27	0.10	0.06	0.38		2.72	0.62
Water 9/	-	0.02	-	-	-	-	0.02	0.02	0.02	-	-		0.35	-
Chemicals 10/	-	-	-	-	-	-	-	-	-	-	0.51		-	0.12
Maint. Labor & Materials 12/	0.96	0.19	1.06	0.52	0.63	0.05	0.74	0.39	0.39	0.59	0.27		2.60	0.40
Royalty	-	-	-	0.34 13/	-	-	-	-	-	- 18/	-		-	-
Other Operating Costs 14/	2.87	0.57	3.17	1.57	1.89	0.16	2.23	1.17	1.17	1.77	0.81		7.80	1.20
Subtotal	3.97	1.24	4.32	3.22	2.59	0.34	3.91	2.16	1.99	2.82	2.17		13.87	2.54
Interest 15/	1.53	0.30	1.69	0.84	1.01	0.09	1.19	0.63	0.63	0.95	0.43		4.16	0.64
TOTAL ANNUALIZED COST	5.50	1.54	6.01	4.06	3.60	0.43	5.10	2.79	2.62	3.77	2.60		18.03	3.18
CREDITS														
Returned Alumina 16/	-	-	-	(0.04)	(0.10)	(0.05)	-	-	-	(0.04)	-		-	-
Returned F Values 17/	-	-	-	(9.15)	(0.74)	(0.38)	-	-	-	(9.15)	-		-	-
TOTAL CREDITS	-	-	-	(9.19)	(0.84)	(0.43)	-	-	-	(9.19)	-		-	-
NET ANNUALIZED COST	5.50	1.54	6.01	(5.13)	2.76	0.00	5.10	2.79	2.62	(5.42)	2.60		18.03	3.18

* Control device unit capacities are assumed at 10,000 acfm for dry units and 7,000 acfm for wet units.

** Based on 10 million acfm of equipment capacity.

Footnotes follow Table 8.4c

TABLE 8.4c

COST ELEMENTS - HSS SODERBERG MODELS

EQUIPMENT DESIGNATOR	PRIMARY CONTROL SCHEMES *							SECONDARY CONTROL **	
		WESP	CFPB-5	ST	FBWS			SS	
Equipment Name / Cost Component	Primary Collection	Wet Electrostatic Precipitator	Cross Flow Packed Bed (5 Ft Deep)	Spray Tower	Floating Bed Wet Scrubber	Water Treatment (Lime)		Spray Screen	Water Treatment (Lime)
CAPITAL COST, $/Annual Ton Al									
Purchase Cost 1/	34.02 4/	57.00	8.18	4.34	7.99	6.08 5/		19.98	8.00 5/
Direct Installation 2/	↓	42.75	8.18	4.34	7.99	↓		19.98	↓
Indirect Installation 3/		29.93	4.91	2.60	4.79			11.98	
TOTAL CAPITAL COST	34.02 4/	129.68	21.27	11.28	20.77	6.08 5/		51.94	8.00 5/
ANNUALIZED UNIT, $/Ton Al									
Operating Labor & Materials	0.08 7/	0.03 6/	0.31 7/	0.31 7/	0.31	0.20 7/		0.40 6/	0.20 6/
Electric Power 8/	0.43	0.51	0.51	0.29	0.61	0.44		2.72	0.62
Water 9/	-	-	0.02	0.02	0.02	-		0.35	-
Chemicals 10/	-	-	-	-	-	0.54		-	0.07 11/
Maint. Labor & Materials 12/	1.70	6.48	1.06	0.56	1.04	0.30		2.60	0.40
Other Operating Costs 14/	5.10	19.45	3.19	1.69	3.12	0.91		7.80	1.20
Subtotal	7.31	26.47	5.09	2.87	5.10	2.39		13.87	2.59
Interest 15/	2.72	10.37	1.70	0.90	1.66	0.49		4.16	0.64
TOTAL ANNUALIZED COST	10.03	36.84	6.79	3.77	6.76	2.88		18.03	3.23
CREDITS									
Returned Alumina 16/	-	-	-	-	-	-		-	-
Returned F Values 17/	-	-	-	-	-	-		-	-
NET ANNUALIZED COST	10.03	36.84	6.79	3.77	6.76	2.88		18.03	3.23

* Control device unit capacities are assumed at 60,000 acfm each, corresponding to 70,000 acfm dry hot gas entering.

** Based on 10 million acfm of equipment capacity.

Footnotes follow.

Footnotes - Tables 8.4

1/ Purchase cost from capacity - cost curves and tables in Appendix 8B.

2/ Direct installation cost factored from purchase cost.

3/ Indirect installation cost equal to 30 percent of the sum of purchase and installation costs.

4/ Based upon Singmaster & Breyer estimates for courtyard systems summarized in Table 8.3.

5/ Based on 1970 costs of facilities to neutralize acid liquor - \$130 per gallon per minute of treated liquor. Water treatment capacity required for a primary scrubber system is less than for a secondary scrubber for equivalent aluminum output.

6/ Estimated from industry questionnaire data.

7/ Based on estimated direct labor manhours at \$5.35 distributed according to the following table:

Description	Operating Labor $/Ton of Aluminum	
Dry Device		
Unloading collected solids		.03
Wet Device		
Sump cleaning, nozzle changing, pipe cleaning	.18	
Monitoring wet-dry device combination	.13	
		.31
Primary Collection		
Straightening and changing, cell hood shields		.08
Water Treatment		
Monitoring water treatment plant		.20

8/ Based on 6 mills per kwh.

9/ Based on \$0.013 per 1000 gallons.

10/ Based on using lime at \$18.00 per ton (90% CaO) delivered. This cost for primary systems varies ± \$0.02 depending on HF removal efficiency of the scrubber and assumes prior dry collection of solid fluoride. (In the Pacific Northwest lime is reported (1971) to cost \$25 per ton.)

11/ This figure and corresponding totals apply where a smelter includes both primary and secondary collection and removal systems. Where a smelter includes only a secondary control system, these costs are increased by $0.52 per ton. Small variations introduced by differing efficiencies among control schemes are averaged.

12/ Based on 5% of total capital cost.

13/ This figure represents the sum of the licensee's schedule of declining payments reduced to a present value, assuming an interest rate of 8% and converted to a schedule of uniform payments over an indefinite period; it applies to a smelter of 264,000 tons annual capacity. For a 35,000 ton per year smelter, the corresponding payment is $0.46 per ton aluminum.

14/ Based on 15% of total capital cost with taxes and insurance at 2%, administration at 5% and depreciation at 8%.

15/ Based on a continuing debt equal to total capital cost with interest at 8%.

16/ Based on a value of $0.032 per pound of aluminum returned dry to the cells.

17/ Based on a value of $0.25 per pound of contained F returned dry to the cells.

18/ A technical know-how fee is included in the capital cost.

19/ Cost estimates for the FBDS and IADS systems are derived from data given by exclusive suppliers of these systems on a turnkey basis.

8.3 Cost Effectiveness of Control Models

To compare the cost effectiveness of the various emission control schemes represented by the models, the component costs from Tables 8.4 have been summed and tabulated against the overall control efficiency predicted for each model control scheme. These data are shown in Tables 8.5.

Control schemes known to be in current plant use for the indicated potline applications are underlined in Tables 8.5 and their control efficiencies are derived from reported data. Efficiencies for the other potentially applicable schemes were developed from test data or from fractional removal efficiency curves for the equipment.

The tabulation of the performance of the model control schemes, representing the application of the most effective available kinds of effluent removal equipment, illustrates the strong influence of collection or hooding efficiency on overall control efficiency, and the cost effectiveness relationships illustrate the orders of magnitude of costs associated with various control efficiency levels for the different potline types. Control schemes using primary control alone are limited in overall control efficiency to the value of the collection efficiency. If secondary scrubbers are added to primary systems, overall control efficiencies ranging in the high 90's can be achieved even with relatively low collection efficiency but at increased cost.

Table 8.5a

COSTS AND OVERALL CONTROL EFFICIENCIES

PREBAKE POTLINES - MODEL I

Model Scheme No.	Control Scheme* Primary Stage 1	Control Scheme* Primary Stage 2	Control Scheme* Secondary	Model Costs, $/ton Al Capital	Model Costs, $/ton Al Annualized Unit	Model Costs, $/ton Al Annualized Credit	Model Costs, $/ton Al Annualized Net	Overall Control Eff. Total F Collection Eff. η_c = 96.0	Overall Control Eff. Total F Collection Eff. η_c = 85.6
IA-1	FBDS	-	-	60	19.80	10.50	9.30	94.6	84.4
-2	MC	VS	-	51	19.70	4.30	15.40	93.8	83.6
-3	MC	HPSS-3	-	53	18.70	4.30	14.40	92.1	82.1
-4	DESP	ST	-	49	15.80	5.20	10.60	92.4	82.3
-5	MC	CFPB-5	-	43	14.20	4.30	9.90	89.6	80.0
-6	MC	ST	-	35	11.90	4.30	7.60	85.2	76.0
-10	CFDS	-	-	53	17.30	10.00	7.30	89.6	80.0
-11	MC	-	-	25	7.90	4.30	3.60	32.2	26.7
-12	ST	-	-	32	10.80	-	10.80	85.2	75.9
-13	MC+DESP	ST	-	52	16.90	5.20	11.70	89.2	79.6
-14	MC	VPB-3	-	37	12.60	4.30	8.30	71.8	64.0
-15	MC	FBWS	-	42	14.20	4.30	9.90	87.2	77.2
-16	CS	-	-	37	12.10	-	12.10	83.0	74.0
-17	IADS	-	-	55	17.00	10.50	6.50	94.1	84.0
IB-1,9	FBDS	-	SS	106	35.90	10.50	25.40	96.5	91.1
-2,9	MC	VS	SS	94	35.00	4.30	30.70	95.7	90.3
-3,9	MC	HPSS-3	SS	96	34.00	4.30	29.70	94.0	88.8
-4,9	DESP	ST	SS	92	31.10	5.20	25.90	94.3	89.0
-5,9	MC	CFPB-5	SS	86	29.50	4.30	25.20	91.5	86.7
-6,9	MC	ST	SS	78	27.20	4.30	22.90	87.1	82.7
								All Effluent to Sec.	
IC-7	-	-	CFPB-3	68	22.50	-	22.50	92.5	
-8	-	-	FBWS	99	32.40	-	32.40	85.2	
-9	-	-	SS	43	15.30	-	15.30	72.1	

Underlined equipment designators signify equipment in current use on prebake potlines.

* Legend follows Table 8.5c.

Table 8.5b

CONTROL SCHEME COSTS AND OVERALL CONTROL EFFICIENCY

VSS SODERBERG POTLINES - MODEL II

Model Scheme No.	Control Scheme*			Model Costs, $/ton Al				Overall Control Eff. Total F $\eta_c = 80.4$
	Primary		Secondary	Capital	Annualized			
	Stage 1	Stage 2			Unit	Credit	Net	
IIA-1	ST	WESP	-	49	15.60	-	15.60	79.6
-2	FBDS	-	-	30	9.70	9.20	0.50	79.5
-3	DESP	ST	-	41	13.20	0.80	12.40	79.5
-4	MC	VS	-	40	13.60	0.40	13.20	79.4
-5	MC	HPSS-3	-	33	11.30	0.40	10.90	78.4
-6	MC	CFPB-5	-	33	11.10	0.40	10.70	78.0
-8	ST	-	-	28	9.60	-	9.60	74.6
-9	IADS	-	-	31	9.30	9.20	0.10	78.7
IIB-1,7	ST	WESP	SS	109	36.80	-	36.80	93.8
-2,7	FBDS	-	SS	90	31.00	9.20	21.80	93.7
-3,7	DESP	ST	SS	101	34.40	0.80	33.60	93.7
-4,7	MC	VS	SS	100	34.80	0.40	34.40	93.6
-5,7	MC	HPSS-3	SS	93	32.50	0.40	32.10	92.6
-6,7	MC	CFPB-5	SS	93	32.30	0.40	31.90	92.2

Underlined equipment designators signify equipment in current use on VSS Soderberg potlines.

*Legend follows Table 8.5c.

Table 8.5c

CONTROL SCHEME COSTS AND OVERALL CONTROL EFFICIENCY

HSS SODERBERG POTLINES - MODEL III

Model Scheme No.	Control Scheme*			Model Costs, $/ton Al				Overall Control Eff. Total F c = 85.6
	Primary Stage 1	Primary Stage 2	Secondary	Capital	Unit	Credit	Net Unit	
IIIA-1	CFPB-5	WESP	-	191	56.50	-	56.50	83.9
-2	ST	WESP	-	181	53.50	-	53.50	81.3
-3	CFPB-5	-	-	61	19.70	-	19.70	78.0
-4	ST	-	-	51	16.70	-	16.70	70.2
-5	FBWS	-	-	61	19.70	-	19.70	76.9
IIIB-1,6	CFPB-5	WESP	SS	251	77.80	-	77.80	90.4
-2,6	ST	WESP	SS	241	74.80	-	74.80	87.8
-3,6	CFPB-5	-	SS	121	41.00	-	41.00	84.5

Underlined equipment designators signify equipment in current use on HSS Soderberg potlines.

* Legend follows.

Legend for tables 8.5a, b and c

CFPB-5	Cross Flow Packed Bed Scrubber (5 ft. Deep)
CFPB-3	Cross Flow Packed Bed Scrubber (3.25 ft. Deep)
CS	Chamber Scrubber
DESP	Dry Electrostatic Precipitator
FBDS	Fluidized Bed Dry Scrubber
FBWS	Floating Bed (Bouncing Ball) Wet Scrubber
HPSS-3	High Pressure Spray Screen (3-Stage)
IADS	Injected Alumina Dry Scrubber
MC	Multiple Cyclone
SS	Spray Screen
ST	Spray Tower
VPB-3	Vertical Flow Packed Bed Scrubber (3 ft. Deep)
VS	Venturi Scrubber
WESP	Wet Electrostatic Precipitator

References - Section 8

8.1/ Less, L.N. and Waddington, J., "The Characteristics of Aluminum Reduction Cell Fume", Light Metals 1971, Proceedings of Symposia, 100th AIME Annual Meeting, New York, March 1-4, 1971.

8.2/ U.S. Department of Health, Education and Welfare, "Control Techniques for Particulate Air Pollutants" AP-51, National Air Pollution Control Administration, January 1969.

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9.0 Analysis of Control and Improvement By Industry Models

In Section 7.0 of this report, effluent and emission data obtained concerning the various plants in the primary aluminum industry were presented as industry totals and weighted averages to conform with the restrictions on the confidentiality of individual plant data under which responses were made.

To permit systems analysis of the control and improvement of the process variations within the industry, individual process models (representing capacity and production portions of the total) have been structured specific to the various and differing control problems. (See Section 8). These model types and schemes, combined in the proportions of capacity tonnages representative of industry practice, are totaled to provide an overall industry model. Operations on individual segments of the model may then be made to effect systems analyses of the industry as a whole. The degree of industry control can be analyzed and costed, and effect of improvement in individual process segments of the total industry can be evaluated.

By considering the factors involved in altering one model to another of higher performance characteristics, estimates may be made with respect to the cost and practicability of the pollution abatement control of the total industry, or of its major segments. Such estimates are developed in Section 9.3.

Direct comparison between an individual plant and the model system representing a process and/or control grouping is not intended. The models are hypothetical and are representative of the achievable performance levels of the various components that are, or may be, assembled to treat typical sets of plant conditions. Operating and equipment parameters of actual installations will, in each plant case, deviate from these conditions. Calculated model performances may be used only as a guide to those to be expected in actual practice.

9.1 Potential Industry Control Practice in Terms of 1971 Capacity by Models

Table 9.1 shows the comparative relationships among levels of control effectiveness of the portions of the total United States aluminum industry represented by the individual cell type models and methods of collecting effluents, as the industry was structured at the end of 1971.

9.1.1 Control by Cell Type

The analysis indicates that prebake anode plants (Model I) accounted for about 65 percent of the total aluminum capacity in 1971, and that their total emission control was approximately 74 percent. These plants accounted for about 66 percent of the industry potential emissions of total fluorides, including the emissions from one plant which exercised no control over potroom effluents.

VSS Soderberg plants (Model II) accounted for about 13 percent of the total aluminum capacity and about 9 percent of the total fluoride emissions. The general overall emission control exercised in these plants was approximately 83 percent.

HSS Soderberg plants as a group comprise 22 percent of the total aluminum capacity and were responsible for 26 percent of the potential total fluoride emissions. Overall emission control efficiency was lower (70 percent) than in the other types of plants.

The industry model as a whole showed a 74 percent overall emission control with respect to total fluorides.

9.1.2 By Collection Type

Considering the breakdown into the methods of effluent collection utilized by the industry in the model types, Table 9.1 shows that less than 3 percent of the aluminum capacity of the industry was in prebaked potlines without emission control, accounting for about 10 percent of the total fluoride emissions from the industry potlines.

Table 9.1

DISTRIBUTION OF EMISSION CONTROL, 1971,
BY ANODE CONFIGURATION AND COLLECTION TYPES

Model		Aluminum Capacity 1000 Tons	Tons Total Fluoride Effluent	Tons Total Fluoride Emissions	% Overall Control Efficiency	Emissions Lb/1000 lb Al
I-A	(Prebake Primary Only)	2,160	49,680	11,341	77.2	5.3
I-B	(Primary and Secondary)	100	2,300	398	82.7	4.0
I-C	(Secondary Only)	638	14,674	3,567	75.7	5.6
I-D	(Uncontrolled)	122	2,806	2,806	0	23.0
I	All Prebake Potlines	3,020	69,460	18,112	73.9	6.0
II-A	(VSS Primary Only)	410	9,430	2,134	77.4	5.2
II-B	(Primary and Secondary)	191	4,393	272	93.8	1.4
II	All VSS Soderberg	601	13,823	2,406	82.6	4.0
III-A	(HSS Primary Only)	1,033	23,759	7,056	70.3	6.8
Industry		4,654	107,042	27,574	74.2	5.9

Controlled emission prebake potlines (62 percent of total aluminum capacity) released 56 percent of total industry fluoride emissions. The greater portion of these prebake potlines employ primary collection and control only, with overall control efficiency amounting to 77 percent of cell effluent. A somewhat better control efficiency (83 percent) is obtained on the smaller tonnages of prebake lines employing both primary and secondary control in separate collection systems. Lines from which total collection to a secondary system is effected without the use of primary hooding treat about 21 percent of the prebaked capacity tonnage, (14 percent of total capacity), and achieve about 76 percent control efficiency.

On the VSS Soderberg production (13 percent of total capacity) overall control efficiency is 77 percent for those lines using primary collection only which account for 68 percent of the VSS Soderberg tonnage. Overall collection efficiency is 94 percent for lines using both primary and secondary control on 32 percent of the VSS Soderberg tonnage.

All HSS Soderberg capacity (22 percent of total) is in potlines with primary collection and control only, and overall emission control efficiency is relatively low, at 70 percent. HSS Soderberg capacity accounts for 26 percent of the industry fluoride emissions.

9.1.3 By Emission Control Scheme

The analysis of model performance of the sections of the industry which correspond to the emission control schemes in use on the three types of potlines is shown in Tables 9.2 and 9.3.

Prebake Potlines (Table 9.2) have been separately divided into "old" and "new" cell categories* with different levels of primary collection efficiency as noted in the previous section. The "new" group accounts for the smaller (21 percent) portion of prebake cell capacity, and the effluent is treated in primary collection/control systems with an overall control efficiency of 85 percent.

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* See pages 8-6 and 8-7 for definitions.

Table 9.2

DISTRIBUTION OF EFFLUENT CONTROL, 1971, BY CONTROL SCHEMES PREBAKE POTLINE CAPACITY

Model No.	Equipment Designator*		Percent Total Capacity	Percent Total F Emission	Overall Control Efficiency	Emission Rate, lb F /1000 lb Al
	Prim.	Sec.				
IA (New)*						
-1	FBDS		6.5	1.4	94.6	1.2
-15	MC+FBWS		3.9	1.9	87.2	2.9
-10	CFDS		1.9	0.8	80.0	2.4
-11	MC		1.5	3.9	32.2	15.6
IA(New)	Subtotal		13.8	8.0	85.0	3.4
IA (Old)*						
-6	MC+ST		12.9	12.0	76.0	5.5
-1	FBDS		7.3	4.4	84.4	3.6
-4	DESP+ST		3.5	2.4	82.3	4.1
-11	MC		3.5	9.9	26.7	16.9
-13	MC+DESP+ST		2.6	2.0	79.6	4.7
-10	CFDS		1.5	1.2	80.0	4.6
-16	CS		0.8	0.9	74.0	6.0
-12	ST		0.3	0.3	75.9	5.5
-14	MC+VPB-3		0.1	0.2	64.0	8.3
IA (Old)	Subtotal		32.5	33.3	73.6	6.1
IA Total			46.3	41.3	77.0	5.3
IB-6,9 (Old)	MC+ST	SS	2.1	1.4	82.7	4.0
IC-7		CFPB-3	2.4	0.7	92.5	1.7
-9		SS	11.3	12.2	72.1	6.4
IC Total			13.7	12.9	75.7	5.6
ID	None		2.6	10.1	0	23.0
Total Model I (PB)			64.9	65.8	73.9	6.0

* Definitions follow Table 9.3, page 9-7.

Table 9.3

DISTRIBUTION OF EFFLUENT CONTROL, 1971, BY CONTROL SCHEMES VSS AND HSS SODERBERG POTLINE CAPACITY AND INDUSTRY TOTAL

Model No.	Equipment Designator*		Percent Total Capacity	Percent Total F Emission	Overall Control Efficiency	Emission Rate, lb F /1000 lb Al
	Prim.	Sec.				
VSS Potlines						
IIA-4	MC+VS		3.8	3.0	79.4	4.7
-8	ST		3.8	3.7	74.6	5.8
-1	ST+WESP		1.3	1.0	79.5	4.7
IIA Subtotal			8.8	7.7	77.4	5.2
IIB-1,7	ST+WESP	SS	4.1	0.1	93.8	1.4
Total Model II (VSS)			12.9	8.7	82.6	4.0
HSS Potlines						
IIIA-9	ST		22.2	25.5	70.3	6.8
Total Industry			100.0	100.0	74.3	5.9

* Definitions follow.

Legend for Tables 9.2 and 9.3

CFPB-3	Cross Flow Packed Bed Scrubber (3.25 ft. Deep)
CS	Chamber Scrubber
DESP	Dry Electrostatic Precipitator
FBDS	Fluidized Bed Dry Scrubber
FBWS	Floating Bed (Bouncing Ball) Wet Scrubber
MC	Multiple Cyclone
SS	Spray Screen
ST	Spray Tower
VPB-3	Vertical Flow Packed Bed Scrubber (3 ft. Deep)
VS	Venturi Scrubber
WESP	Wet Electrostatic Precipitator

For definitions of "New" and "Old", see page 8-6

The "old" prebake group, comprising about 32 percent of the total industry capacity, is largely under primary collection/control only, with overall control efficiency of 73 percent. It is noted that in this group the production tonnage represented by Model IA-11 contributes 10 percent of the total industry emissions from less than 4 percent of the industry tonnage: overall control efficiency is very low compared to the rest of the group, and no attempt is made in this control scheme to remove gaseous fluorides from the potline effluents.

Better emission control (83 percent) is obtained on the small portion of "old" cell capacity in which a secondary control system is used to supplement the primary (IB-6,9). Production in which all prebake effluent is treated by secondary control only (Models IC), represents 14 percent of the total tonnage and emits 13 percent of the total fluorides of the industry, achieving 76 percent emission control.

The contribution to the total fluoride emission inventory by the production elements using various control schemes on prebake potline effluents varies quite widely. Emission rates for the better controlled conditions of the newer lines range between 1.2 and 2.9 pounds total fluoride per 1000 pounds of aluminum produced. The corresponding range for older type installation with primary collection only is 4 to 6 pounds, excluding the one model group (IA-11) which is greatly in excess of the rest.

VSS Potlines emission control schemes are compared in Table 9.3. Control of primary effluent alone results in overall emission control efficiency of 75-80 percent as applied to 9 percent of the industry capacity, and contributes 8 percent of the total industry emission inventory. A marked improvement in control is shown for the plants which collect and treat VSS potline effluert in both primary and secondary systems. The resulting emission rate of this group is about 1.4 pounds of total fluorides per 1000 pounds of aluminum produced.

HSS Soderberg Potlines utilize only one control scheme, of which the overall control efficiency is about 70 percent. HSS capacity is 22 percent of the industry total, and accounts for 26 percent of the industry emission inventory of total fluorides.

9.2 Industry Control Costs in Terms of 1971 Capacity by Models

The unit cost and capital cost of present industry control can be estimated from the models by summing the cost elements of the various collection, removal, and treatment schemes of the models which are detailed in Section 8.0, and applying these model costs to the corresponding industry tonnages after adjusting for differences in flow rate between actual plants and the flow rates assumed for the models.

Table 9.4 presents this estimate for the model breakdown of capacity tonnages of the 1971 industry. It is noted that this estimate is constructed from derived, not reported data as explained in Section 8. Direct cost comparison with individual plants is not justified because plants may incorporate several models in their operations, and individual operating conditions will vary from the models.

The derived industry costs given in Table 9.4 include cost elements which were not accounted for in the industry responses to the questionnaire (Section 7.3). Model capital investment totals include indirect installation costs amounting to 30 percent of the sum of purchase and direct installation costs for equipment. When this adjustment is made to the reported industry investment, the agreement with the industry model is good, and the model capital cost may be regarded as being conservative.

Model net annual costs include allowances for capital recovery costs amounting to 23 percent of the total capital cost for depreciation, interest, administration, taxes and insurance. Applying these allowances to the reported industry direct operating costs reconciles them with the estimate constructed from the industry models.

Table 9.4

1971 ALUMINUM INDUSTRY COSTS FOR CONTROL BY MODELS

Model No.	Equipment Designator		Capacity 1000 Tons	Flow Adjustment Factor	Model Capital Cost		Model Annualized Cost	
	Prim.	Sec.			Unit $/Cap'y Ton	Total MM$	Unit $/Ton	Total MM $/yr
IA-1 (N)	FBDS	-	302	1.00	60	18.1	9.30	2.8
IA-1 (O)	FBDS	-	338	1.00	60	20.3	9.30	3.1
IA-4 (O)	DESP+ST	-	165	1.30	64	10.5	13.80	2.3
IA-6 (O)	MC+ST	-	601	1.12	39	23.6	8.50	5.2
IA-10 (N)	CFDS	-	90	1.00	53	4.8	7.30	0.7
IA-10 (O)	CFDS	-	70	1.00	53	3.7	7.30	0.5
IA-11 (N)	MC	-	70	1.12	28	2.0	4.10	0.3
IA-11 (O)	MC	-	163	1.23	31	5.1	4.60	0.9
IA-12 (O)	ST	-	15	1.82	58	0.9	19.70	0.4
IA-13 (O)	MC+DESP+ST	-	120	1.00	52	6.2	11.70	1.4
IA-14 (O)	MC+VPB-3	-	6	0.97	36	0.2	8.00	0.1
IA-15 (N)	MC+FBWS	-	180	1.17	49	8.8	11.60	2.1
IA-16 (O)	CS	-	40	1.32	49	2.0	16.00	0.7
IB-6,9 (O)	MC+ST	SS	100	1.20	100	10.0	29.40	2.9
IC-7	-	CFPB-3	112	1.00	72	8.1	23.80	2.7
IC-9	-	SS	526	1.00	48	25.2	16.90	8.9
ID	-	-	122	-	0	0	0	0
Model I (Prebake)			3,020	-	50.11	149.3	11.59	35.0
IIA-1	ST+WESP	-	60	1.00	49	2.9	15.60	0.9
IIA-4	MC+VS	-	175	1.00	40	7.0	13.20	2.3
IIA-8	ST	-	175	1.15	32	5.6	11.00	2.0
IIB-1,7	ST+WESP	SS	191	1.16	109	20.8	42.70	8.0
Model II (VSS)			601	-	60.50	36.4	21.96	13.2
IIIA-9 (HSS)	ST	-	1,033	1.00	49	50.6	16.70	17.2
Total Industry			4,654		50.77	236.3	14.05	65.4

9.3 Improvement in Industry Emission Control

The effectiveness and costs of improving the present level of overall emission control of the industry can be evaluated by selectively upgrading individual model schemes to others of higher performance, applying the unit cost increments involved to the capacity tonnages represented by the model modification, and then reconstructing the cost and emission model of the total industry.

Emission data have similarly been applied to capacity tonnages, resulting in the analysis representing improvement in emission control under conditions of full production. Operation at less than full capacity would reduce the cost effectiveness (pounds of emission reduction per dollar of capital cost) of the upgrading.

For the purpose of this evaluation, added cost and performance improvement estimates have been made to improve air pollution abatement in the existing aluminum industry from its present overall control efficiency of approximately 74 percent to four higher levels of performance, to wit:

> Raise all plants to a minimum 80 percent overall control efficiency.
>
> Apply best demonstrated primary control technology in all plants.
>
> Raise all plants to a minimum 90 percent overall control efficiency.
>
> Apply the best demonstrated technology, both primary and secondary, to all plants.

In performing these upgrading analyses, no judgment has been made as to their economic feasibilities.

In raising overall control efficiency to the intermediate levels, model schemes have been modified with consideration given to the least capital investment required to effect the level of improvement; in the optimum performance case, some models require investments which may be considered out of proportion to the improvements realized.

The analysis is made by taking each of the model schemes represented by an industry segment, determining the new model scheme represented by modification required to reach the new control level, calculating the unit costs of the model scheme conversion, and obtaining the incremental costs for that segment. Emissions are recalculated from the overall control efficiency of the new model, and industry costs and emissions combined to determine cost effectiveness.

For determining the costs of upgrading the models it is assumed that, in most cases, modifications will be made and new ducting added to the primary collection systems amounting to an arbitrary 160 percent of the estimated cost for main ducting in courtyard systems. It is further assumed that, when elements of existing control systems are changed from one type to another, the original element will be either bypassed without cost, or will be removed to provide physical space for the new element. In the latter case the net cost of demolition, including salvage credit, is estimated to be 75 percent of the direct installation cost of equipment removed.

Capital and annualized costs for upgraded segments of the industry are developed from the model costs shown in Tables 8.4 with adjustments to allow for the fact that the installation of a piece of control equipment in an existing plant costs more than the installation of the same equipment in a new plant. It has been assumed that upgraded capital costs are 15 percent higher than new construction. This is reflected as a 12 percent penalty on annualized cost.

It is recognized that these cost assumptions can only be applied to the general case of model modification, and that they may not be applicable to individual plant modification. They are considered to be valid in structuring the overall industry model costs.

In the upgrading of model schemes it was not considered practical to overcome the inherent limitations imposed by the existing types of prebake collection systems; no attempt was made to upgrade the collection efficiency of the older generation of prebake potlines to that of the new, as the cost of such structural modification is both major and indeterminant for the models.

However, a plant, faced with the need to improve its overall control efficiency, may determine that provisions for improved collection efficiency give greater benefit for the capital expenditure than the installation of some types of new removal equipment.

A sample calculation, illustrating the development of costs to upgrade the overall control efficiency in one segment of the existing aluminum industry, is given in Appendix 9A.

The summary of the results of the various upgrading analyses is shown in Table 9.5. Working from a base of an industry model of the capacity available for production in 1971 and its control costs and effectiveness, improvement of industry control to a minimum of 80 percent can be realized by modification of ten of the twenty-two models at an investment of $237 million. (Ref. Table 9.6) Industry emission rate is reduced from 5.9 to 3.7 pounds total fluoride per 1000 pounds aluminum produced at capacity and at an average added cost of $21 per ton aluminum, applied to the modified segment of the industry.

Conversion of the United States plants to incorporate the best demonstrated control on primary gas streams without the addition of secondary control would raise the industry average efficiency from 74 to 86 percent. Fourteen of the twenty-two models would be affected at an added capital cost of $314 million. The average cost of producing aluminum at these fourteen plants would increase by about $18 per ton. (Ref. Table 9.7) An examination of the cost effectiveness parameters for improved models, shown in Table 9.5, suggests that this project may be more attractive than others. Based on net annualized cost per ton of aluminum produced at plant capacity, this alternative shows the highest capture of effluent F per dollar spent for pollution control, 1.6 pounds per dollar.

Raising industry control to a minimum 90 percent level would involve modification of eighteen of the twenty-two models at a cost of $477 million, and result in reduction of the industry emission rate from 5.9 to 2.2 pounds total fluoride per 1000 pounds of aluminum. The added operating cost of this improved control would be $35 per ton, applied to the modified plant. (Ref. Table 9.8)

TABLE 9.5

SUMMARY OF PERFORMANCE AND COSTS UPGRADING EMISSION CONTROL

	Base	Min. 80% OCE			Best Primary			Min. 90% OCE			Best Technology		
	1971 Industry	Unchanged	Modified Segment	Total Industry	Unchanged	Modified Segment	Total Industry	Unchanged	Modified Segment	Total Industry	Unchanged	Modified Segment	Total Industry
Annual Capacity, 1000 Tons Al	4,654	1,903	2,751	4,654	1,443	3,211	4,654	695	3,959	4,654	191	4,463	4,654
Annual Effluent, 1000 Tons Al	107	44	63	107	33	74	107	16	91	107	4	103	107
Annual Emission, 1000 Tons Al	27.5	5.7	11.4	17.1	4.5	10.8	15.3	1.1	8.7	9.8	0.3	7.7	8.0
Emission Rate, lb F/1000 lb Al	5.9	3.0	4.1	3.7	3.1	3.4	3.3	1.6	2.2	2.2	1.4	1.8	1.8
Overall Control Efficiency	74.3	87.0	82.0	84.0	86.4	85.3	85.6	93.4	90.3	90.5	93.8	92.1	92.2
Capture Rate, lb F/1000 lb Al	17.1	20.0	18.9	19.3	19.9	19.6	19.7	21.4	20.8	20.8	21.6	21.2	21.2
Capital Investment													
Total Before Upgrade, MM$	236	121	115	236	97	139	236	51	185	236	21	215	236
Added Total, MM$		-	237	237	-	257	257	-	477	477	-	576	576
Total After Upgrade, MM$		121	352	473	97	396	493	51	662	713	21	791	812
Unit Before Upgrade, $/Ton	51	64	42	51	67	43	51	73	47	51	110	46	51
Added Unit		-	86	50	-	80	55	-	120	102	-	129	124
Unit After Upgrade, $/Ton		64	128	101	67	123	106	73	167	153	110	177	175
Annualized Cost													
Total Before Upgrade, MM$/Year	65	29	36	65	25	40	65	14	51	65	8	57	65
Added Total, MM$/Year		-	58	58	-	55	55	-	133	133	-	139	139
Total After Upgrade, MM$/Year		29	94	123	25	95	120	14	184	199	8	196	204
Unit Before Upgrade, $/Ton	14	15	13	14	17	13	14	20	13	14	42	13	14
Added Unit, $/Ton		-	21	12	-	17	11	-	34	29	-	31	30
Unit After Upgrade, $/Ton		15	34	26	17	30	26	20	47	43	42	44	44
Cost Effectiveness, lb F Captured/$ Spent													
Capital Investment	0.7	0.6	0.3	0.4	0.6	0.3	0.4	0.6	0.2	0.3	0.4	0.2	0.2
Annualized Cost	2.6	2.9	1.1	1.5	2.3	1.3	1.5	2.2	0.9	1.0	1.0	1.0	1.0

Maximum control within limits of best demonstrated technology would require a capital investment in modification of all but one of the models amounting to $584 million and an added operating cost of $32 per ton of aluminum. Under these conditions, total industry emissions could be reduced to a rate of 1.8 pounds total fluoride per ton aluminum. At this level, total investment by the industry in emission control would be more than 800 million dollars, and net operating cost of air pollution control would be some $43 per ton of aluminum.

This analysis illustrates the sharply rising costs involved as higher levels of emission control are achieved by the industry.

9.3.1 Improvement in Overall Control Efficiency to a Plant Minimum of 80 Percent

Table 9.6 indicates the results of performance and cost analyses to upgrade ten of the industry models, representing 59 percent of the total aluminum capacity, so that all plants achieve at least 80 percent overall control efficiency. The average control efficiency of these ten models increases from about 66 percent to 82 percent with a resulting total industry efficiency of 84 percent.

9.3.2 Improvement in Overall Control Efficiency by the Application of Best Primary System Control

If all models of the United States aluminum industry were to adopt the best demonstrated control on primary collection streams, fourteen models representing 69 percent of the capacity, would be modified as indicated in Table 9.7. Their average control efficiency would increase from about 69 percent to more than 85 percent, boosting the total industry efficiency to nearly 86 percent.

TABLE 9.6

UPGRADING INDUSTRY MODELS
MINIMUM OVERALL CONTROL EFFICIENCY 80%

Old Model No.	Cap'y 1000 Tons	Old OCE, %	New Model No.*	New OCE, %	Annual Emission, Tons F			Capital Investment						Annualized Costs					
								Unit, $/Ton			Total, MM$			Unit, $/Ton			Total, MM$/Year		
					Old	New	Decrease	Old	Add	New	Old	Add	New	Old	Add	New	Old	Add	New
IA-6(O)	601	76.0	IA-5	80.0	3,318	2,765	553	39	31	70	23.6	18.6	42.2	8.50	3.30	11.80	5.2	2.0	7.2
IA-11(N)	70	32.2	IA-6	85.2	1,092	238	854	28	12	40	2.0	0.8	2.8	4.10	4.48	8.58	0.3	0.3	0.6
IA-11(O)	163	26.7	IA-5	80.0	2,748	750	1,998	31	20	51	5.0	3.3	8.3	4.60	5.15	9.75	0.9	0.8	1.7
IA-12(O)	15	75.9	IA-5	80.0	83	69	14	58	46	104	0.9	0.7	1.6	19.70	(0.19)	19.51	0.4	0.0	0.4
IA-14(O)	6	64.0	IA-5	80.0	50	28	22	36	18	54	0.2	0.1	0.3	8.00	2.50	10.50	0.1	0.0	0.1
IA-16(O)	40	74.0	IA-5	80.0	239	184	55	49	26	75	2.0	1.0	3.0	16.00	5.80	21.80	0.7	0.2	0.9
IC-9	526	72.1	IA-6,9	84.6	3,375	1,863	1,512	48	40	88	25.2	21.1	46.3	16.90	8.58	25.48	8.9	4.5	13.4
ID	122	0	IA-5	80.0	2,806	561	2,245		49	49		6.0	6.0		11.08	11.08		1.4	1.4
IIA-8	175	74.6	IIB-8,7	88.8	1,022	451	571	32	69	101	5.6	12.1	17.7	11.00	23.75	34.75	2.0	4.2	6.2
IIIA-9	1,033	70.3	IIIA-2	81.3	7,056	4,443	2,613	49	167	216	50.6	172.9	223.5	16.70	42.68	59.38	17.2	44.1	61.3
Upgraded Segment	2,751	65.6		82.0	21,789	11,352	10,437	42	86	128	115.1	236.6	351.7	12.90	20.90	33.80	35.7	57.5	93.2
Total Industry	4,654	74.2		84.0	27,648	17,137	10,437	51	50	101	236.4	236.6	473.0	14.05	12.36	26.41	65.4	57.5	122.9

* Definitions follow Table 9.9, page 9-21

TABLE 9.7

UPGRADING INDUSTRY MODELS
BEST PRIMARY CONTROL

Old Model No.	Cap'y 1000 Tons	Old OCE, %	New Model No.*	New OCE, %	Annual Emission, Tons F			Capital Investment						Annualized Costs					
								Unit, $/Ton			Total, MM$			Unit, $/Ton			Total, MM$/Year		
					Old	New	Decrease	Old	Add	New	Old	Add	New	Old	Add	New	Old	Add	New
IA-6(O)	601	76.0	IA-1	84.4	3,318	2,156	518	39	62	101	23.6	37.3	60.9	8.50	2.64	11.14	5.2	1.6	6.8
IA-10(N)	90	89.6	IA-1	94.6	215	112	103	53	62	115	4.8	5.6	10.4	7.30	3.12	10.42	0.7	0.3	1.0
IA-10(O)	70	80.0	IA-1	84.4	322	251	71	53	62	115	3.7	4.3	8.0	7.30	3.12	10.42	0.5	0.2	0.7
IA-11(N)	70	32.2	IA-1	94.6	1,092	87	1,005	28	60	88	2.0	4.2	6.2	4.10	7.12	11.22	0.3	0.5	0.8
IA-11(O)	163	26.7	IA-1	84.4	2,748	585	2,163	31	65	96	5.0	10.6	15.6	4.60	7.12	11.72	0.9	1.2	2.1
IA-12(O)	15	75.9	IA-1	84.4	83	54	29	58	93	151	0.9	1.4	2.3	19.70	(.86)	18.84	0.4	0.0	0.4
IA-13(O)	120	82.3	IA-1	84.4	563	431	132	52	61	113	6.2	7.3	13.5	11.70	(1.83)	9.87	1.4	(0.2)	1.2
IA-14(O)	6	64.0	IA-1	84.4	50	22	28	36	55	91	0.2	0.3	0.5	8.00	2.64	10.64	0.1	0.0	0.1
IA-15(N)	180	87.2	IA-1	94.6	530	224	306	49	67	116	8.8	12.1	20.9	11.60	0.12	11.72	2.1	0.0	2.1
IA-16(O)	40	74.0	IA-1	84.4	239	144	95	49	58	107	2.0	2.3	4.3	15.00	(1.33)	14.67	0.7	0.0	0.7
IC-9	526	72.1	IB-1,9	91.1	3,375	1,077	2,298	48	69	117	25.2	36.3	61.5	16.90	10.41	27.31	8.9	5.5	14.4
ID	122	0	IA-1	84.4	2,806	438	2,368	-	69	69	-	8.4	8.4	-	10.41	10.41	-	1.3	1.3
IIA-8	175	74.6	IIA-3	79.5	1,022	825	197	32	27	59	5.6	4.7	10.3	11.00	3.90	14.90	2.0	0.7	2.7
IIIA-9	1,033	70.3	IIIA-2	81.3	7,056	4,443	2,613	49	167	216	50.6	122.9	173.5	16.70	42.68	59.38	17.2	44.1	61.3
Upgraded Segment	3,211	69.3		85.3	27,775	10,849	11,926	43	80	123	138.6	257.7	396.3	12.58	17.13	29.71	40.4	55.2	95.6
Total Industry	4,654	74.2		85.6	27,648	15,407	12,241	51	55	106	236.4	257.7	494.1	14.05	11.86	25.91	65.4	55.2	120.6

* Definitions follow Table 9.9, page 9-21

9.3.3 Improvement in Overall Control Efficiency to a Plant Minimum of 90 Percent

Eighteen models representing 85 percent of the total industry capacity would need to be upgraded to achieve at least 90 percent control efficiency in all plants. Table 9.8 details the most economical changes as developed in the model analysis. Only three of the twenty-two existing control models now achieve 90 percent or better.

9.3.4 Improvement in Overall Control Efficiency to the Best Demonstrated Technology

Of the twenty-two model control schemes, twenty-one could be improved, usually by both changing the primary control equipment and adding secondary control. One model, IIB-1,7, a VSS Soderberg potline with spray tower plus wet electrostatic precipitator on the primary stream and a spray screen secondary control, is now achieving about as good overall control at 93.7 percent as present technology can demonstrate. Table 9.9 shows the projected performances and costs for upgrading 96 percent of the industry to best demonstrated technology.

9.4 Future Control Costs 1975-2000

To estimate the future costs of pollution control in the primary aluminum industry several premises are used as developed in earlier parts of this report.

The production capacity used as a base is the median of the capacity projections made in Section 2, Figure 2.6. This median capacity projection is illustrated in Figure 9.1 which also shows the range of the capacity estimate.

Control costs are a function of the levels of control applied to the capacity, and the industry model costs developed in Section 9.3 have been applied to the 1971 capacity as reference points for the projection of industry capital investment.

TABLE 9.8

UPGRADING INDUSTRY MODELS
MINIMUM OVERALL CONTROL EFFICIENCY 90%

Old Model No.	Cap'y 1000 Tons	Old OCE, %	New Model No.*	New OCE, %	Annual Emission, Tons F			Capital Investment						Annualized Costs					
								Unit, $/Ton			Total, MM$			Unit, $/Ton			Total, MM$/Year		
					Old	New	Decrease	Old	Add	New	Old	Add	New	Old	Add	New	Old	Add	New
IA-1(O)	338	84.4	IB-1,9	91.1	1,208	689	519	60	60	120	20.3	20.2	40.5	9.30	17.98	27.28	3.1	6.1	9.2
IA-4(O)	165	82.3	IB-4,9	89.0	672	417	255	64	60	124	10.5	9.8	20.3	13.80	17.98	31.78	2.3	3.0	5.3
IA-6(O)	601	76.0	IB-4,9	89.0	3,318	1,521	1,797	39	83	122	23.6	49.6	73.2	8.50	21.19	29.69	5.2	12.7	17.9
IA-10(O)	70	80.0	IB-4,9	89.0	322	177	145	53	99	152	3.7	6.9	10.6	7.30	21.67	28.97	0.5	1.5	2.0
IA-11(N)	70	32.2	IB-5,9	91.5	1,092	137	955	28	82	110	2.0	5.7	7.7	4.10	24.95	29.05	0.3	1.8	2.1
IA-11(O)	163	26.7	IB-4,9	89.0	2,478	412	2,336	31	98	129	5.0	16.0	21.0	4.60	25.67	30.27	0.7	4.2	4.9
IA-12(O)	15	75.9	IB-4,9	89.0	83	38	45	58	96	154	0.9	1.4	2.3	19.70	17.70	37.40	0.4	0.3	0.7
IA-13(O)	120	82.3	IB-13,9	86.3	563	378	185	52	49	101	6.2	5.9	12.1	11.70	17.39	29.09	1.4	2.1	3.5
IA-14(O)	6	64.0	IB-4,9	89.0	50	15	35	36	80	116	0.2	0.5	0.7	8.00	21.19	29.19	0.1	0.1	0.2
IA-15(N)	180	87.2	IB-15,9	89.1	530	451	79	49	49	98	8.8	8.9	17.7	11.60	17.39	28.99	2.1	3.1	5.2
IA-16(O)	40	74.0	IB-4,9	89.0	239	101	138	49	96	95	2.0	3.8	5.8	16.00	20.35	36.35	0.7	0.8	1.5
IB-6,9(O)	100	84.6	IB-4,9	89.0	398	253	145	100	35	135	10.0	3.5	13.5	29.40	4.02	33.42	2.9	0.4	3.3
IC-9	526	72.1	IB-4,9	89.0	3,375	1,331	2,044	48	57	105	25.2	30.0	55.2	16.90	11.79	28.69	8.9	6.2	15.1
ID(O)	122	0	IB-4,9	89.0	2,806	309	2,497	-	106	106	-	12.9	12.9	-	28.96	28.96	-	3.5	3.5
IIA-1	60	79.5	IB-1,7	93.8	283	86	179	49	69	118	2.9	4.1	7.0	15.60	23.75	39.35	0.9	1.4	2.3
IIA-4	175	79.4	IB-4,7	93.6	829	258	571	40	93	133	7.0	16.3	23.3	13.20	30.49	43.69	2.3	5.3	7.6
IIA-8	175	74.6	IB-1,7	93.8	1,022	250	772	32	69	101	5.6	12.1	17.7	11.00	23.75	34.75	2.0	4.2	6.2
IIIA-9	1,033	70.3	IIIB-1,6	90.4	7,056	2,281	4,775	49	261	310	50.6	296.4	347.0	16.70	74.04	90.74	17.2	76.5	93.7
Upgraded Segment	3,959	70.9		90.3	26,324	8,852	17,742	47	120	167	184.6	477.0	661.6	12.88	33.66	46.53	51.0	133.2	184.2
Total Industry	4,654	74.2		90.5	27,648	10,176	17,742	51	102	153	236.4	477.0	713.4	14.05	28.62	42.67	65.4	133.2	198.6

* Definitions follow Table 9.9, page 9-21

TABLE 9.9

UPGRADING INDUSTRY MODELS
BEST DEMONSTRATED TECHNOLOGY

Old Model No.	Cap'y 1000 Tons	Old OCE, %	New Model No.*	New OCE, %	Annual Emission, Tons F			Capital Investment						Annualized Costs					
								Unit, $/Ton			Total, MM$			Unit, $/Ton			Total, MM$/Year		
					Old	New	Decrease	Old	Add	New	Old	Add	New	Old	Add	New	Old	Add	New
IA-1(N)	302	94.6	IB-1,9	96.5	375	243	132	60	60	120	18.1	18.0	36.1	9.30	17.98	27.28	2.8	5.4	8.2
IA-1(0)	338	84.4	IB-1,9	91.1	1,208	689	519	60	60	120	20.3	20.2	40.5	9.30	17.98	27.28	3.1	6.1	9.2
IA-4(0)	165	82.3	IB-1,9	91.1	672	338	334	64	119	183	10.5	19.6	30.1	13.80	16.29	30.09	2.3	2.7	5.0
IA-6(0)	601	76.0	IB-1,9	91.1	3,318	1,230	2,088	39	111	150	23.6	66.7	90.3	8.50	19.51	28.01	5.2	11.9	17.1
IA-10(N)	90	89.6	IB-1,9	96.5	215	72	143	53	111	164	4.8	10.0	14.8	7.30	19.99	27.29	0.7	1.8	2.5
IA-10(0)	70	80.0	IB-1,9	91.1	322	143	179	53	111	164	3.7	7.8	11.5	7.30	19.99	27.29	0.5	1.4	1.9
IA-11(N)	70	32.2	IB-1,9	96.5	1,092	56	1,036	28	109	137	2.0	7.6	9.6	4.10	23.99	28.09	0.3	1.7	2.0
IA-11(0)	163	26.7	IB-1,9	91.1	2,748	334	2,414	31	114	145	5.0	18.6	23.6	4.60	23.99	28.59	0.9	3.6	4.5
IA-12(0)	15	75.9	IB-1,9	91.1	83	31	52	58	143	201	0.9	2.1	3.0	19.20	16.01	35.71	0.4	0.2	0.6
IA-13(0)	120	79.6	IB-1,9	91.1	563	246	317	52	110	162	6.2	13.2	19.4	11.70	15.04	26.74	1.4	1.8	3.2
IA-14(0)	6	64.0	IB-1,9	91.1	50	12	38	36	104	140	0.2	0.6	0.8	8.00	19.51	27.51	0.1	0.1	0.2
IA-15(N)	180	87.2	IB-1,9	96.5	530	145	385	49	116	165	8.8	20.9	29.7	11.60	16.99	28.59	2.1	3.1	5.2
IA-16(0)	40	74.0	IB-1.9	71.1	239	82	157	49	107	156	2.0	4.2	6.2	16.00	15.54	31.54	0.7	0.6	1.3
IB-6,9(0)	100	84.6	IB-1,9	91.1	398	205	193	100	66	166	10.0	6.6	16.6	29.40	2.34	31.74	2.9	0.3	3.2
IC-7	112	92.5	IB-1,7	96.0	192	103	89	72	69	141	8.1	7.7	15.8	23.80	10.11	33.91	2.7	1.2	3.9
IC-9	526	72.1	IB-1,9	91.1	3,375	1,077	2,298	48	69	117	25.2	36.3	61.5	16.90	10.11	27.01	8.9	5.5	14.4
ID	122	0	IB-1,9	91.1	2,806	250	2,556	-	118	118	-	14.4	14.4	-	27.28	27.28	-	3.4	3.4
IIA-1	60	79.5	IIB-1,7	93.8	283	86	197	49	69	118	2.9	4.1	7.0	15.60	23.75	39.35	0.9	1.4	2.3
IIA-4	175	79.4	IIB-4,7	93.6	829	258	571	40	93	133	7.0	16.3	23.3	13.20	30.49	43.69	2.3	5.3	7.6
IIA-8	175	74.6	IIB-1,7	93.8	1,022	250	772	32	69	101	5.6	12.1	17.7	11.00	23.75	34.75	2.0	4.2	6.2
IIIA-9	1,033	70.3	IIIB-1,6	90.4	7,056	2,281	4,775	49	261	310	50.6	269.4	320.0	16.70	74.04	90.74	17.2	76.5	93.7
Upgraded Segment	4,463	73.5		92.1	27,376	8,131	19,245	48	129	177	215.5	576.4	791.9	12.86	31.07	43.83	57.4	138.7	195.6
Total Industry	4,654	74.2		92.2	27,648	8,043	19,245	51	124	175	236.4	576.4	812.8	14.05	29.8	43.9	65.4	138.7	204.1

* Definitions follow.

Components of Upgraded Models, Tables 9.6 to 9.9

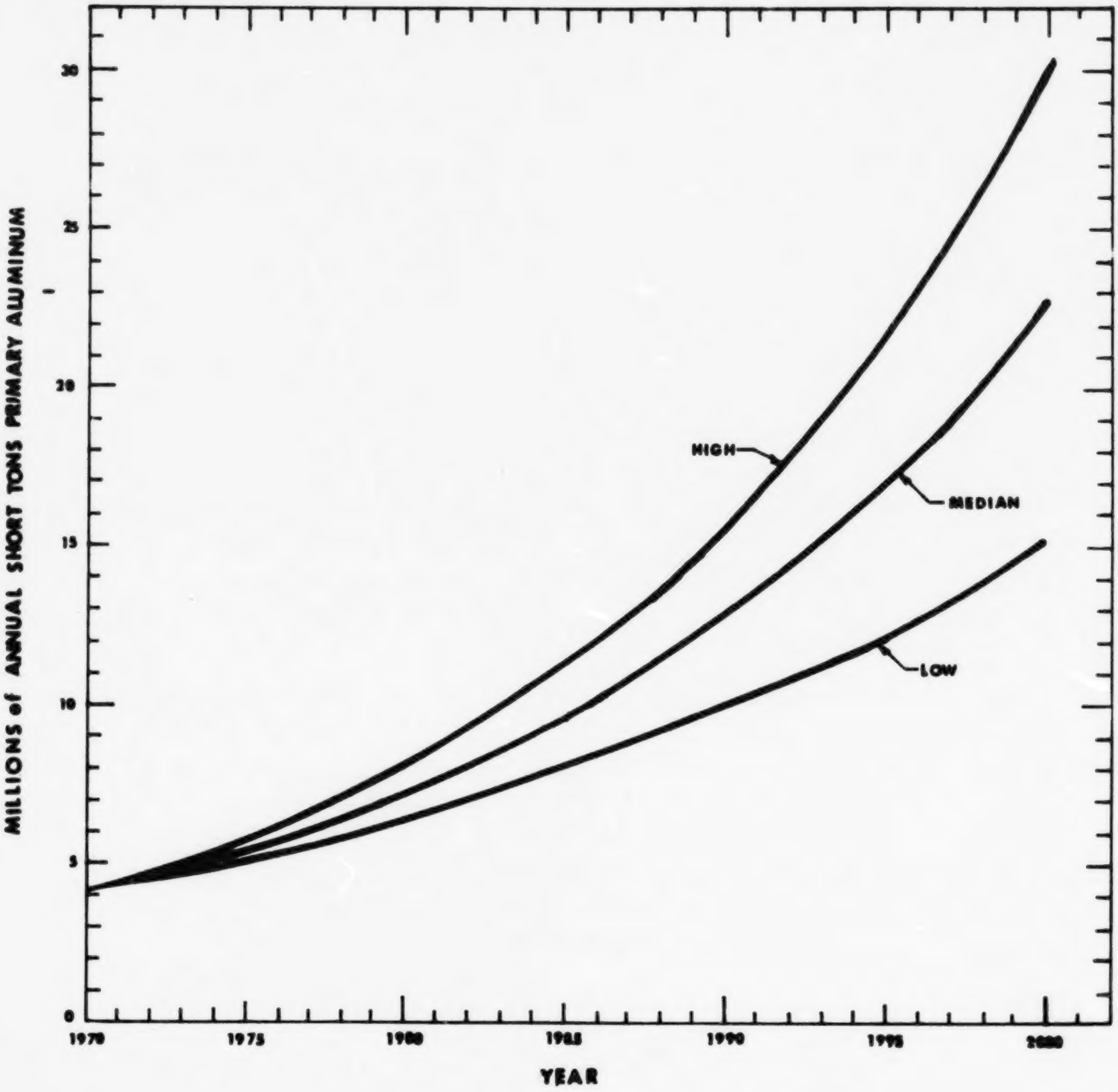
Model	Prim.	Sec.	Description
IA-1	FBDS	-	Fluid Bed Dry Scrubber, Primary only
-5	MC+CFPB-5	-	Multiple Cyclone and Cross Flow Packed Bed Primary
-6	MC+ST	-	Multiple Cyclone and Spray Tower on Primary
IB-1,7	FBDS	CFPB-3	Fluid Bed Dry Scrubber Primary, Cross Flow Packed Bed Secondary
-1,9	FBDS	SS	Fluid Bed Dry Scrubber Primary, Spray Screen Secondary
-4,9	DESP+SP	SS	Dry Electrostatic Precipitator and Spray Tower Primary, Spray Screen Secondary
-5,9	MC+CFPB-5	SS	Multiple Cyclone and Cross Flow Packed Bed Primary, Spray Screen Secondary
-15,9	MC+FBWS	SS	Multiple Cyclone and Floating Bed Wet Scrubber Primary, Spray Screen Secondary
IIA-3	DESP+ST	-	Dry Electrostatic Precipitator and Spray Tower Primary
IIB-1,7	ST+WESP	SS	Spray Tower and Wet Electrostatic Precipitator Primary, Spray Screen Secondary
-4,7	MC+VS	SS	Multiple Cyclone and Venturi Scrubber Primary, Spray Screen Secondary
-8,7	ST	SS	Spray Tower Primary, Spray Screen Secondary
IIIA-2	ST+WESP	-	Spray Tower and Wet Electrostatic Precipitator Primary
IIIB-1,6	CFPB-5 +WESP	SS	Cross Flow Packed Bed and Wet Electrostatic Precipitator Primary, Spray Screen Secondary

FIGURE 9.1

PROJECTED PRODUCTION CAPACITY

U.S. PRIMARY ALUMINUM

1970 to 2000



Two cases are considered for the projection of future costs.

In Case I the assumption is made that all new construction, whether it represents replacement of existing capacity or additional capacity, will be required to control emissions to the level of best demonstrated technology, or 96.5 percent overall control efficiency for these installations.

Two alternative situations are considered under this assumption: a) that existing plants are not upgraded before replacement, and b) that existing plants make the investment required to bring overall emission control of present capacity to the level of best demonstrated technology (92.5 percent) industry average. As capacity replacement occurs, the cumulative investment and operating costs of the total industry under the first alternative will approach those estimated for the limiting case of the second alternative.

In Case II the basic assumption is made that new construction will apply best demonstrated technology to primary control only, with no control on secondary effluent, realizing a 94.6 percent overall control efficiency on new installations.

Again, two alternative situations applying to existing plants are considered: c) that no investment is made in upgrading present control, and d) that investment is made to raise present control to the level of best demonstrated technology on primary collection streams only, with no control of the secondary stream. This later control level is 85.6 percent for the aggregate of existing plants. Similarly to Case I, as capacity replacement occurs, the capital and investment costs of the total industry under the first alternative will approach those estimated for the limiting case of the second alternative as the total industry control increases to 94.6 percent.

The projections also assume that most of the new capacity to be built in the next thirty years will be designed as prebake potlines with high efficiency collection systems. While it is probable that some new VSS Soderberg capacity expansion or new plant construction will take place, the proportion of the total is expected to be small enough that its costs will not have a significant effect on this assumption within the accuracy of the estimation.

Table 9.10 compares the projected costs and control performances, 1971 and 2000, for Cases I and II and the two alternative improvement plans. Future unit capital and unit annualized costs are lower than their corresponding values for an upgraded 1971 industry because, as existing plants are retired they are replaced with new ones having improved control incorporated in the initial construction rather than added to or replacing less efficient systems.

Figure 9.2 shows the two cases of estimated pattern of projected capital investment in emission control to the year 2000, expressed in 1970 dollars. The families of curves represent the different situations expected when starting from the two levels of current investment required to reach the initial industry compliance with the emission control standards noted.

Figure 9.3 shows the corresponding families of annual operating cost curves, projected to the year 2000, expressed in 1970 dollars.

Because all projections are based on the median capacity growth curve, the range of variation of both actual investment and actual cost can be as much as 30 percent, plus or minus, in the latter years of the period considered.

The presentation of these cost projections is not intended as a recommendation for the adoption of the best demonstrated technology regardless of cost but simply as an indication of the estimated costs in 1970 dollars, should such a strategy be adopted.

Table 9.10

PRESENT AND PROJECTED POLLUTION CONTROL PERFORMANCE AND COSTS (1970 DOLLARS)

	1971			2000	
	Present	Best Prim.	Best Tech.	Best Prim.	Best Tech.
Aluminum Capacity, MM Tons	4.7	4.7	4.7	22.5	22.5
F Effluent, M Tons	107	107	107	518	518
Overall Control Efficiency, %	74.3	85.6	92.5	94.6	96.5
F Emission, M Tons	27.5	15.3	8.0	28.0	18.1
Emission Rate, Ton F/M Ton Al	5.9	3.3	1.7	1.2	0.8
Unit Capital Investment, $/Ton	51	106	175	60	103
Total Capital Investment, MM$	238	494	813	1350	2320
Unit Annualized Cost, $/Ton	13	25	43	9	25
Total Annual Cost, MM$	62	116	200	202	553

FIGURE 9.2

PROJECTED INDUSTRY CAPITAL INVESTMENT IN EMISSION CONTROL (1970 DOLLARS) TO THE YEAR 2000

CASE I BEST DEMONSTRATED TECHNOLOGY

CASE II BEST PRIMARY CONTROL

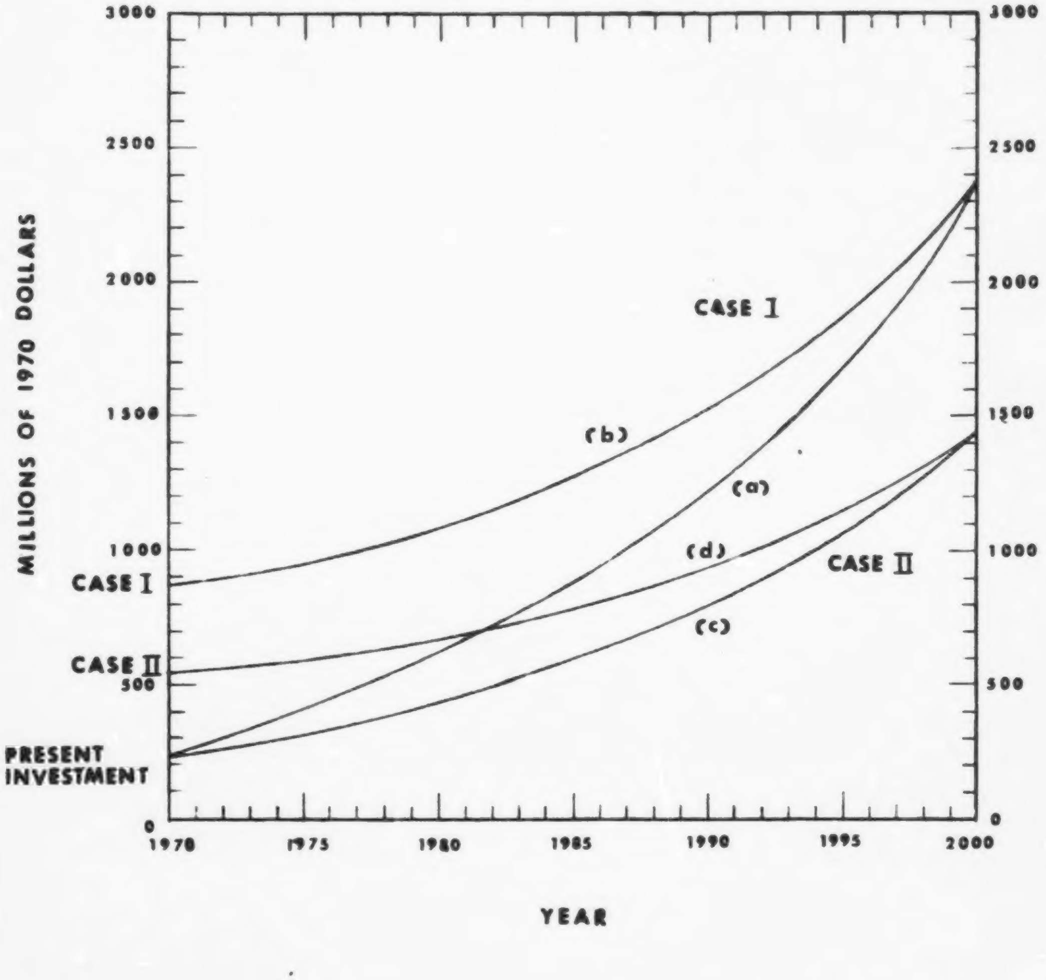
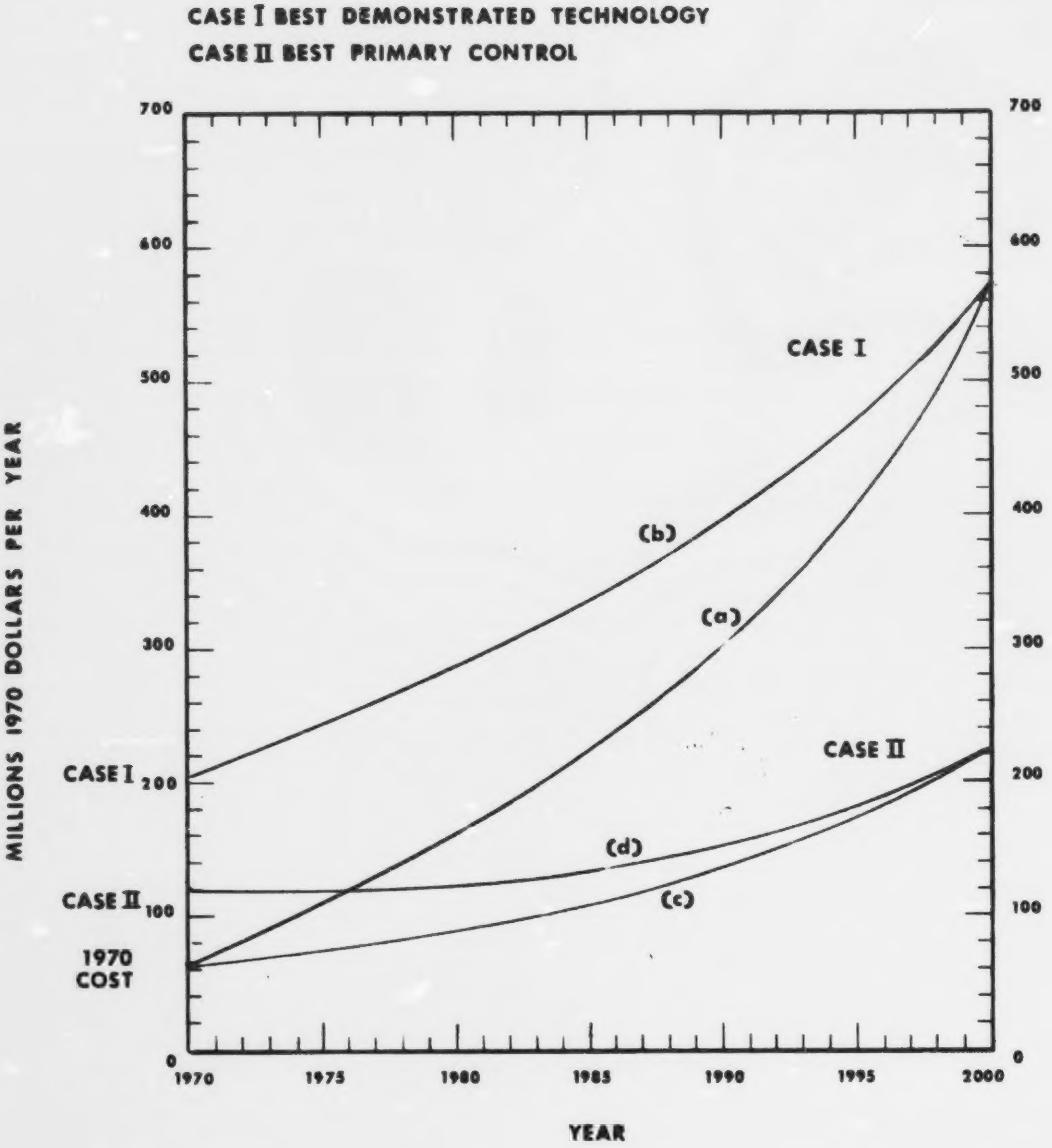


FIGURE 9.3
PROJECTED ANNUAL OPERATING COSTS
FOR EMISSION CONTROL (1970 DOLLARS)
TO THE YEAR 2000



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10.0 Potential Fields for Research and Development in Pollution Abatement

An objective of this study is to determine where research and development may be undertaken to achieve the desired control of emissions to the air from the operations of the primary aluminum industry.

To accomplish that objective, this section summarizes the effluent control problems which exist in the reduction plant processing areas, and evaluates them in terms of relative factors of level of uncontrolled emissions, knowledge of emission problems, extent of available control, and cost impact of control. Priorities and programs are suggested for research and development effort.

10.1 Survey of Problems

The problems involved with the separate effluent sources are briefly summarized below:

1. Carbon Plant Effluents

Carbon plant effluents are, with one exception, large quantities of carbon dust particulates generated by handling, crushing, grinding, sizing and mixing fractions of coke used for the preparation of reduction cell electrodes. Universal practice is to collect these dusts at point of origin and recover them in dry separation equipment. The problem has been reduced to one of in-plant housekeeping. Little quantitative information is available on the dust generation, and control is imperative to obtain a minimum of emission from equipment in normal operating condition.

The use of softened or melted pitch as a paste binder for the carbon particles of the electrodes results in the evolution of an unknown, but minor, quantity of volatile hydrocarbon during processing. The generation is localized, and is considered to be small enough so that normal practice is to exhaust these fumes to atmosphere. The fumes can be largely removed from these exhausts by application of available wet scrubbing technology, although treatment is not usually given to them.

2. Anode Bake Plants

Anode bake plants are a component of nearly all prebake smelters and are associated with approximately 50 percent of the United States production capacity. Minor sources of carbon dust to the atmosphere lie with the mechanical handling of the anode packing materials in the bake pits, and in the blast cleaning of finished anodes before rodding. Both are controlled to empirical limits with local collection and separation systems, the losses constituting a housekeeping, rather than a pollutant problem.

Some volatile hydrocarbons may be released during anode pressing operations, but the amounts are minor and they are exhausted to atmosphere. As with the paste fumes noted above, they can largely be removed by available technology.

The gases from baking furnaces contain, in addition to combustion products, hydrocarbons and limited amounts of SO_2 released from the anode paste by baking, small amounts of fluorides originating in recycled scrap anodes, and smoke. The volume of effluent is large. The amount of condensible hydrocarbons is great enough to constitute a major removal problem. Visible smoke constitutes the major abatement problem and a considerable effort is being directed at controlling it.

3. Anode Rodding

Effluents generated in the anode rodding operations are minor in quantity and are locally controlled through collection and removal by available technology. They consist of dusts arising from spent butt cleaning and crushing operations, dust and metallics caused by blast cleaning of rods, and fumes evolved in melting and pouring thimbles for rod resetting. Control does not present a major problem.

4. Potline Materials Handling

Bulk handling of alumina and of bath materials generates particulate dusts at transfer points which, if uncontrolled, represent both material losses and industrial hygiene problems. Control is exercised by enclosure, collection, and dry recovery, usually in baghouse systems. No quantitative information is available on emission losses, but good control can be maintained with existing technology.

5. Potroom Effluents

Problem

Reduction cell effluents include fluoride and nonfluoride particulates, gaseous fluorides, CO and CO_2, SO_2, and varying amounts of volatilized hydrocarbons. If uncontrolled, these effluents may result in damaging levels of fluorides and significant levels of other pollutants. Much attention has been given to the fluoride aspects of the control problem, and only incidental attention to the emission of SO_2 and CO, on which there is little information.

Level of Control

For prebake potlines, a high level of control of total particulates and gaseous fluorides in collected effluent streams is achievable with currently available technology. The larger portion of the total effluent of prebake cells may be collected by local hooding at the cells; emissions may be controlled by dry adsorption of gaseous fluorides on alumina and subsequent essentially complete removal of particulates from the gas stream. With optimum primary collection efficiency, treatment of the remaining cell effluent in a secondary collection and control system in much larger volume contributes relatively little (2 percent) to overall control efficiencies.

A control level of 95 percent is obtainable with primary control only on effluents from the prebake cells representing some 15 percent of total industry capacity whose design permits installation of nearly completely effective cell hooding. On other prebake cells (some 50 percent of industry capacity) hooding efficiency is lower, and the attainment of overall emission control in the 90-95 percent range would require either improved collection efficiency or the additional use of secondary collection and effluent treatment.

VSS cells, which represent some 14 percent of industry capacity, present air pollution abatement problems similar to those of prebake cells, since burner combustion of tar fogs emitted from the VSS cells practically eliminates these constituents. The primary collection efficiency is lower than with the fully hooded prebake cells, and secondary effluent treatment is required to reach an overall control efficiency range comparable to the best control performance achievable with prebakes.

HSS cells differ in their effluent control problems from the other types of cells. Hydrocarbon fumes, not removable by direct combustion as in VSS cells, condense to tars which interfere with high efficiency dry control systems. Unless hooding and operational techniques can be modified to achieve acceptable levels of primary collection, secondary removal systems would be required for high levels of overall emission control. Wet devices can be used which are capable of obtaining good efficiency for the 20 percent of industry capacity represented by HSS installation.

Cost of Control

Present potline emission control is estimated to account for about 6 percent of total plant investment of $800-$900 per annual capacity ton with a range of 4-14 percent for this figure in individual installations. The net annualized cost of current emission control is 3-5 percent of a nominal production cost of $390 per ton, with a range of 1-9 percent in individual installations. The emission control achieved with present installations is of the order of 73-80 percent.

The effect on capital and production costs of upgrading control in existing plants to best demonstrated control technology in new plants, is shown in Table 9.5.

It is evident that the impact of potline emission control on capital and operating costs is substantial, and is significantly greater on HSS installations than on prebake or VSS plants. Capital cost impact is greater in upgrading existing plants, where conversions are involved, than on new plants constructed with highly efficient emission control systems. Costs for individual plants vary widely, and can be a factor in their competitive position with respect to other domestic producers, as well as to foreign producers which may have lighter control cost burdens.

6. Hot Metal Operations

Removal of metal from the cells is carried out in closed systems with little evolution of pollutant fumes in tapping, ladle skimming, hot metal transfer to the cast house, retention in holding furnaces, alloying to adjust metal composition, or casting.

Fluxing of hot metal to remove impurities carried over with the cell metal produces copious, but intermittent, quantities of gas and fumes which vary in composition with fluxing practice and are potential air pollutants. Gases include HCl, occasional chlorine, nitrogen and inert carriers. Fumes are primarily aluminum chloride, which may hydrolyze to alumina and hydrochloric acid. Little or no specific information is available on amounts and composition of the effluents, which are collected in hooding systems and exhausted through empirically designed fume removal equipment.

7. Power Generation

Although aluminum smelters consume very large blocks of base load electric power, few generate it in company-owned power plants. One company uses gas turbines and gas-fired boiler steam turbines to generate power and a few use gas-fueled piston engines. Gas is a clean burning fuel, essentially free from sulfur, but nitrogen oxides and CO may present pollution problems. Little has been done to control these.

10.2 Priorities

An assessment of air pollution abatement problems facing the primary aluminum industry suggests that the sources of emissions derive from five process areas which can be ordered in rank of priority as regards the desirability of developing better control. Factors influencing the selection of priorities include the levels of currently uncontrolled emission, the extent to which control techniques exist, costs for achieving control, and the state of knowledge of the problem. Considering these factors, three pollutant sources present higher priority problems than the other two:

1. Potline effluents from side-worked prebake, VSS Soderberg and HSS Soderberg cells,
2. Anode bake furnace effluents,
3. Potline effluents from center-worked prebake cells.

Other emission sources are not considered to present the same order of magnitude of potential pollution. However, investigation of two of them with respect to their character and composition could be included in a second order priority. These are:

4. Cast House fluxing,
5. Paste mixing.

10.3 Priority Problems and Possible Solutions

Priority 1

Cell Effluents

Arranged in the approximate order in which positive results appear to be most likely to be realized, the investigative areas concerning improved pollution emission control over cell effluents are:

a) Improvement in Hooding and Collection Systems

As explained in Section 8.1.3, the efficiency with which cell effluents are collected at the cells and ducted to removal equipment has a strong impact on the overall control efficiency of most potline control schemes. Reported primary collection efficiencies range from about 70 percent to higher than 96 percent, and perhaps the most dollar-effective way to improve pollution abatement within the industry would be to develop improved collection technology at the poorer installations. Hood designs which minimize openings, ventilation systems which permit greatly increased gas flow from cells which have hoods open, and potroom supervision which assures that hoods are kept in place and in good repair, all contribute to high collection efficiency.

At present, hoods are not used on VSS Soderberg cells; only effluents entering the skirt are treated in primary control systems. Cell enclosure in addition to the skirt would improve collection efficiency.

Soderberg anode fumes normally pass directly into the potroom. Although the hydrocarbons might complicate removal equipment, the collection and treatment of these fumes would improve overall control and would alleviate the industrial hygiene problems of tar fog in the potroom.

b) Reduction of Fluoride Effluents from Hall-Heroult Cells

Short of eliminating fluorides from the smelting process, measures to reduce the quantity of effluents from the cryolite bath of Hall-Heroult cells may prove effective and economical ways to abate the air pollution problem.

These measures include experimental programs to better define and quantify the electrochemical interreaction in the cell bath during electrolysis, and development work on the mechanical aspects of cell operations which result directly or indirectly in the generation of cell effluents.

They also include investigations which would provide a sound basis for the extrapolation of the results of small-scale cell experiments on the effect of changes in bath ratio, alumina concentration, and bath temperature on fluoride effluent rates.

c) Development of Improved Operating Technology

Improvement in the physical operations of cell feeding, working, and tapping which, because they result in the breaking of the cell crust, result in an opportunity for effluents to escape from the bath, is an area for investigative development.

d) Composition of Cell Effluents

While the fluoride component of cell effluents is generally well defined, less has been established concerning the other gaseous components which represent potential pollutants, such as SO_2, CO, and volatilized hydrocarbons. The size distribution, composition, and quantity of solid particulates is not well established, and have an effect on the design and selection of appropriate removal equipment.

Information on the total composition of cell effluents is incomplete, particularly with respect to potential pollutants other than fluorides. Data on character, composition, and quantity of hydrocarbons is sparse, as is information on SO_2 and CO_2. The amount of hydrolyzation occurring in practice and the resultant state transfer of fluorides affecting removal mechanisms is not satisfactorily known. Investigation into these areas would improve the knowledge of the conditions under which pollutant removal is to be effected.

e) Particle Size Analysis

The prediction of removal efficiency for many kinds of particulate control equipment depends on knowledge of the particle size distribution of the pollutant entering the equipment. Measurement of effective particle diameter and the weight distributions of micron and submicron dusts is uncertain and subject to difficulties in obtaining reproducibility of results. A well-supported project aimed at developing accurate methods of determining particle size distributions in aluminum potline and bake furnace effluents, particularly in the submicron ranges, and at correlating these distributions with particulate removal equipment performance would provide valuable information by which equipment design might be refined and improved.

f) Particulate Agglomeration

There is strong evidence that some particulates in potline effluent streams tend to agglomerate during their passage from cell to removal equipment. Few quantitative data exist and little is known about the factors favoring agglomeration. A substantial experimental research project could be performed at several kinds of potlines to develop information which might assist the design of more efficient particulate removal equipment.

g) Particulate Solubilities

The capacity of wet scrubbers to remove gaseous fluorides may become limited by the concentration of the fluorine ion, and this in turn may become controlled by the solubilities of fluoride particulates. A limited effort at determining particulate solubilities at various temperatures and in various liquors might provide useful data.

h) Hydrocarbon Volatilization, Condensation and Oxidation

Basic research into the behavior and characteristics of various hydrocarbons used in the making of anodes and cathodes, particularly Soderberg type anodes, could yield insight into better ways to control the gases and fumes evolved during baking of anodes, both in bake plants and in Soderberg cells. Better information on volatilization rates, condensation temperatures and characteristics, and on oxidation rates could help in formulating anode paste with improved properties as regards pollution control.

i) HF and Scrubber Liquor Solutions

Maximum removal efficiency of wet scrubbers for gaseous fluorides is sometimes limited by the vapor pressure of HF in the scrubber solution. This occurs when the scrubber liquor is at a neutral or acid pH. Data are sparse on vapor pressures and solubilities of HF in water, lime water, and caustic solutions at relatively low concentrations.

j) Capture of Submicron Particulates

Although filters and electrostatic precipitators may be designed to capture submicron particulates efficiently, wet scrubbers, generally low in submicron removal efficiency, may be better suited to some kinds of effluents, such as those from HSS potlines and bake furnaces. Improvement in cost-effectiveness in the submicron ranges would be very desirable.

k) Removal Efficiency on Very Dilute Streams

Pollutant concentrations, both particulate and gaseous, in secondary gas streams, especially when primary cell collection efficiency is high, may be only a hundredth as great as concentration in the primary streams - equivalent to the discharge from a 99 percent efficient removal device on the primary. Present technology does not offer equipment at reasonable cost which is capable of high removal efficiency on these dilute streams.

Priority 2

Anode Baking Effluents

Development work is needed in the control of the anode baking effluents.

The composition of the baking plant gases is not well defined, and even the major potential pollutants are only incompletely identified at most plants. Because of the considerable quantities of condensible hydrocarbon fumes in the effluents, satisfactory control is difficult and may present a problem. Large volumes of gases complicate sampling and control.

In general the problem areas are similar to those of the HSS cell effluents; incomplete information on character and composition of both gaseous and particulate components, control of effluent generation and the physical state of the particulates contained in the effluents.

Priority 3

Cast House Fluxing

A lower priority is assigned to the investigation of effluent control applied to gases and fumes from fluxing operations in cast houses. While emission control might be improved by a more quantitative understanding of the effluent composition, specific removal of chlorine, and greater efficiency in elemination of submicron particulates from the emissions, the problem is less important than that of either cell room or anode baking effluents. The potential pollution and the cost impact of pollution control are relatively minor.

Priority 4

Paste Mixing

Volatile hydrocarbon fumes released during hot processing of pitch binders represent a minor, but potential air pollutant of undetermined effect. Little, if any, emission control is practiced. The problem needs to be better defined with respect both to the quantitative and qualitative aspect of the effluent and to the applicability of existing control devices. Cost impact of problem solution is relatively small.

10.4 Research and Development Subject Areas

The solutions of the major air pollution problems in the industry identified earlier in this section require research and development work in several general subject areas to generate more and better information. These areas are:

Measurement and sampling
Improved Characterization of Effluents
Reduction in Effluent Generation
Elimination of Fluoride Pollutants
Improved Effluent Collection
Improved Pollutant Removal

The following section presents a general discussion of these areas in relation to the major pollutant problems and suggests specific research and development projects concerned with them.

1. Measurement and Sampling

One of the problems encountered in this study has been the difficulty in obtaining consistent or complete data concerning the volumes and composition of the effluent streams. The data are highly variable; the sampling and analytical methods are not uniform, and there are limited data on a number of effluent parameters.

Relatively low volume gas streams such as those in primary cell collection systems are moved at moderate velocities and are sufficiently uniform that measurement and sampling can be accomplished with reasonable confidence.

The effluent streams of secondary collection systems and anode baking gases may be orders of magnitude greater in volume, much lower in velocity, and may in both cases be subject to wide variation in pollutant loading over considerable time spans and intervals.

Unpowered flows of secondary potroom effluents pass through large cross-sectional areas at very low velocities, which are measurable only with sensitive anemometers; air flow distribution can be erratic, compounding the difficulty of utilizing a sufficient number of sampling points and sampling determinations on which to confidently base extrapolations to total air flows.

Powered exhausts of air flow, as in controlled secondary potroom systems, reduce the flow measurement problem and more accurate data are obtainable, but still require use of a multiplicity of sampling points to gauge the results of non-uniform flows in the system.

Representative sampling of the large volume flows is difficult. Very large samples are required to obtain accurate estimation of the pollutant loadings, per unit of volume, which are both low and variable.

The confidence which can be placed in data obtained from this type of gas volume sampling is not great, and efforts are recommended to improve the techniques and practice. Project 1, Development of Improved Techniques for Gas Volume Sampling, is suggested to implement this recommendation.

Sampling of pollutants which are carried in the effluent streams is accomplished by passing the sample through a train which separates the constituents for analysis. Difficulties leading to analytical inaccuracies arise in the simultaneous collection of tar fumes with other particulates, and in adsorption of gaseous fluorides on particulates during the sample collection, among others. Project 2, Improved Techniques in Pollutant Sampling of Effluent Streams, is suggested for research and development effort to improve the reliability of pollutant sampling.

2. Improved Characterization of Effluents

The attention in the aluminum industry with respect to air pollution has been largely focused on fluorides and particulates in cell effluents; only minor effort has been made to evaluate the occurrence of other potential pollutants in the various plant effluents. Reliable data on the amount, size, and composition of particulates, and amount and composition of gaseous components is less than complete for primary cell effluents, and very sparse for other effluent flows.

Identification of potential pollutants such as SO_2, CO, volatile hydrocarbons is necessary and determination of these pollutant amounts is needed to adequately evaluate their contribution to the problem. Reliable information concerning particulate size distributions and better data on relative proportions of particulate composition is basic to improvement in the emission controls applied.

This information acquisition is desirable on all effluent streams identified, but particularly so on the large volume effluents from primary and secondary cell collection and anode baking, and on the effluents from paste processing and cast house fluxing. Such activity will require the cooperative participation by various aluminum companies representing the full range of processing operations. Given access to the processing equipment itself, investigators would be able to obtain the necessary analyses.

Project 3, Characterization of Emissions from Potrooms, and Project 4, Characterization of Effluents from Anode Baking, are examples of high priority undertakings of this type.

3. Reduction in Effluent Generation

Short of elimination of potential pollutants from the effluent stream, development of measures to reduce their generation in the processing segment can result in reducing the magnitude of the air pollution problem.

As noted earlier in this report, some experimental research results have been published on the various factors influencing the quantities and characteristics of aluminum reduction cell effluents. The major aluminum producers have also investigated various aspects of the process affecting effluents as a part of basic research programs designed to improve the economics and efficiency of metal production, and they have developed understandings of the cell operating conditions which yield high current efficiency and ease of operation. Conditions which minimize pollutant effluent may not be compatible with stable and efficient cell operation. Although it has been shown that changes in cell operating conditions can have marked influence on effluent generation, details of cell operating parameters are among the most jealously guarded secrets in the highly competitive aluminum smelting industry and there is little likelihood that the foreseeable future will bring much disclosure in this field. The reduction of effluent generation by adjustments in cell operating conditions is an aim of most producers but it probably will not prove acceptable as a subject for publicly disclosed research and development because the work would be too closely associated with technology which affects directly the profitability of aluminum production.

Aside from cell operating parameters, three areas of investigation with the objective of reducing pollutants carried in potroom effluents include:

a) Provision to keep VSS Soderberg burners ignited;

b) Provision to install new prebake anodes with a minimum of pollutant escape;

c) Improved handling of cell feed materials in the potroom.

Project 5, Improvements in Potroom Technology to Reduce Pollutants, is suggested as an approach to research and development activity in this area.

Anode baking is another important effluent source to which attention should be directed to reduce the amounts of potential pollutants.

SO_2 in this effluent originates with the sulfur content of the paste which is released during baking, and of the fuel used for furnace firing. Fluorides originate with bath materials associated with scrap butt anodes returned for recycling. Tar fumes originate with the pitch used for the anode binder. Each of these components is subject to reduction, which may be effected by optimization of materials choice and preparation.

Project 6, Reduction in Anode Baking Pollutants, is suggested as a possible investigation program in this area.

4. Elimination of Fluorides from Aluminum Production

Virtually all commercial production of aluminum is by the Hall-Heroult electrolytic reduction of alumina, characterized by the fact that the electrolyte is a mixture of molten fluorine bearing salts,primarily cryolite, operating at nearly 1000°C. Airborne fluorides, the principal pollutants from the aluminum industry, are derived from this electrolyte and elimination of fluorides from aluminum production would relieve the major part of the air pollution of the industry.

Although no significant departure from the original Hall-Heroult process for the reduction of alumina to aluminum has been achieved on an industrial scale, much development work has been performed in the past thirty years on alternative processes.

Among the avenues which have been explored by major aluminum producers have been the direct reduction of aluminum oxide by carbon in electric furnaces, the reduction of alumina with manganese chloride to form aluminum chloride, followed by conversion to aluminum metal with manganese, electrolysis of fused aluminum chloride, and electrolysis of aluminum sulfides. The direct reduction processes produce aluminum-silicon alloys requiring additional processing to recover aluminum metal.

The low cost of producing pure alumina by the Bayer process, the development of improved efficiencies for the Hall-Heroult process, and the existence of many older, fully depreciated plants using the Hall-Heroult process make it difficult to develop an economical competitive process. However, it may be that, taking the pollution aspects of the Hall-Heroult process into consideration, another process which does not evolve fluorine effluents may become attractive. An acceptable new process would have to be one that produces little toxic effluents or one where the toxic effluents could be easily treated and removed.

Although replacement of the Hall-Heroult process by another might ease air pollution problems, this is not recommended as a proposed research and development project because no potentially successful process has been identified.

5. Improved Effluent Collection

Control of pollutant emissions is contingent on the collection, as well as the treatment, of the effluents concerned, and in most process areas effluent collection is good, or can be made so by application of existing suitable design techniques. The process area in which this statement is not entirely applicable is that of the potlines, where the results of improvement can contribute significantly to improvement in control.

There is current need for the development of better hoods and collection systems, particularly for Soderberg cells, which will operate at higher efficiency without seriously hampering the primary business of potroom operations, that of producing aluminum.

It is expected that development programs designed to improve cell collection would require close cooperation with producers to achieve practically applicable results. The interrelation of hooding designs with potline operability imposes restrictions on hooding modifications.

Project 7, Improvements in Cell Effluent Collection, deals with this problem, which is placed high on a priority list because of its potential cost effectiveness as applied to a large proportion of the industry.

6. Improved Pollutant Removal

The problem of removal of specific pollutants from effluents are common to several of the process segments of an aluminum plant.

Improvement of HF removal over the high level (98-99 percent) obtainable with presently available mechanisms and equipment for wet scrubbing or dry absorption appears to be in the area of fundamental research, rather than development. The priority which might be placed on such effort is low when the potential gain to control is considered. It is therefore disregarded.

Essentially complete removal of particulates from gas streams also is accomplished with combinations of existing equipment when the particulates are dry and non-sticky. Separation of coarse (plus 5 micron) particulates can be made in centrifugal separators such as cyclones, and the finer particles escaping cyclone separation can be removed in baghouses or electrostatic precipitators.

When a portion of the particulate loading is viscid, as may be the case with tar fogs or hydrocarbon condensates, interference with the operation of dry removal equipment results from fouling of separation surfaces with tar agglomeration, and resort must be made to some form of wet treatment. The efficiency of wet scrubbing in particulate removal, a liquid phase absorption mechanism, falls off rapidly with decreasing particle size at constant energy input, and this effect is compounded by the hydrophobic character of the tars.

Project 8, Improvement in Removal of Hydrocarbon Fumes and Particulates from Effluent Streams, is suggested as a specific development program in this problem area.

Removal of SO_2 from aluminum plant effluents presents a difficult problem because of the low concentrations in the gas streams, an order of magnitude lower than occurs in other industrial effluents such as fossil fuel combustion products.

Removal of HCl and gaseous chlorides from cast house fluxing effluents has not been definitely investigated, so far as is known, but needs a relatively low priority of attention.

10.5 Suggested Research and Development Projects

A number of specific research and development projects have been identified which should be considered in a program to accumulate information leading to solution of the priority pollution abatement problems in the primary aluminum industry.

Project 1 - Development of Improved Techniques of Gas Volume Sampling

Scope - Large volume, low velocity effluent streams.

Purpose - To improve accuracy of quantitative determination for large effluent volumes.

Impact - More precise definition of pollutant levels for abatement purposes.

Requirements - In-plant development of specific standard procedures for reproducibility and accuracy of gas sampling in high volume systems; improvement in low velocity gas flow determinations.

Project 2 - Improved Techniques in Pollutant Sampling of Effluent Streams

Scope - Primary and secondary collected cell effluents, anode baking effluents, anode paste effluents, cast house fluxing effluents.

Purpose - To improve discrimination among samples taken for total solids, soluble and nonsoluble fluoride particulates, hydrocarbon particulates, gaseous fluorides, chlorides, SO_2 and CO.

Impact - More precise definition of pollutant levels for abatement purposes.

Requirements - Development of specific standard procedures for reproducible and accurate simultaneous or sequential separation of potential pollutant components carried in effluent gas streams.

Project 3 - Characterization of Pollutants in Cell Emissions

Scope - Total solids, soluble and nonsoluble particulate fluorides, hydrocarbons, gaseous fluoride, SO_2, CO, NO_2 and CO_2 in primary and secondary collected cell effluents.

Purpose - Quantitative determination of composition and character for potential pollutants in cell effluents.

Impact - More precise definition of potential pollutant levels for abatement control purposes.

Requirements - Continuous monitoring of cell effluents from operating aluminum potlines and analysis, including size distribution of particulates, of potential pollutants, using techniques developed in Projects 1 and 2.

Project 4 - Characterization of Pollutants in Anode Baking

Scope - Total solids, particulate and non-particulate hydrocarbons and fluorides, SO_2, CO, NO_2, and CO_2 in anode baking effluents.

Purpose - Quantitative determination of composition and character for potential pollutants in anode baking effluents.

Impact - More precise definition of potential pollutant levels for abatement control purposes.

Requirements - Continuous monitoring of anode baking effluents from operating bake plants and analysis, including size distribution of particulates, of potential pollutants using techniques developed in Projects 1 and 2.

Project 5 - Improvements in Potroom Technology to Reduce Pollutants

Scope - Fluorine evolution from Hall-Heroult electrolysis.

Purpose - Improved correlation between the effect of cell operating variables and gaseous and particulate fluoride generation in cell effluents.

Impact - Reduction of pollutants requiring abatement control.

Requirements - Experimental and plant scale development of devices and operating techniques which will reduce the quantities of pollutants entering control systems.

Project 6 - Reduction in Anode Baking Plant Pollutants

Scope - Fluoride, SO_2, and hydrocarbon evolution from anode baking operations.

Purpose - Reduction in pollutant generation.

Impact - Improvement in pollutant control problem, reduction of fouling problem in tar removal equipment.

Requirements - Development of improved paste formulations, control of sulfur in anode materials, use of binders other than pitch.

Project 7 - Improvement in Effluent Collection at Cells

Scope - Cell collection system designs.

Purpose - Increase of primary cell collection efficiency.

Impact - Improved overall control efficiency.

Requirements - Development of improved cell hooding designs and primary collection of cell effluents at point of origin without interference with cell operations.

Project 8 - Improvement in Removal of Hydrocarbon Fumes and Particulates from Effluent Streams

Scope - Treatment of effluents from Soderberg cells, Soderberg anodes, anode baking, and anode paste operations.

Purpose - Reduction in the interference with the removal of other particulates from gas streams.

Impact - Reduction in fouling problem in ducting and separation equipment; lower maintenance expense, improvement in fine particulate removal.

Requirements - Development of better methods for agglomeration and removal of viscid particulates from gas streams.

10.6 Suggested Research and Development Program

The projects noted above could be organized into an integrated research and development program to be undertaken by or under the sponsorship of the appropriate air pollution abatement office of the government in cooperation with the producing industry.

In planning such a program and obtaining industry cooperation, account must be taken of the keenly competitive relationship among the relatively small numbers of corporate producers. Historically, there has been a minimum of "know-how" exchange between producers, designed to protect operating techniques which are regarded as economically advantageous trade secrets. While these tight information policies are relaxing somewhat with the advent of new producers, the research and development climate is not conducive to participation by outside groups. The projects suggested for the program require access to operations at the least, and for some the direct participation of the operating staffs in the project is highly desirable.

In this situation, careful planning is required to set up acceptable and effective conditions of data access and discrimination which will guard the confidentiality and use of plant information.